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A MANUAL

OF

MATRICULATION ASTRONOMY

(FULLY ILLUSTRATED)

BY

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PREFACE TO THE FIRST EDITION.

THIS Manual, as its title indicates, is prepared primarily to meet the requirements of the Matriculation curriculum of the Bombay University. Scientific knowledge, however, has been advancing so rapidly within the last ten or twelve years that the ordinary reader, too, who wishes to be abreast of the times, finds it necessary to obtain up-to-date information about the essential facts of astronomy and other natural sciences. To such a reader, also, this compilation will be equally useful.

In preparing this book, the most recent works of Lockyer, Ball, Young, Newcomb, Howe, Comstock, Todd, Lowell, Turner, Agnes Clerke, Gore, Fowler, Pickering and others have been consulted.

* * * * * * * * * * * *

To facilitate reference, a list of astronomical definitions has been given at the end. The Test Questions as well as those selected from the science papers of the High Schools n the Bombay Presidency and from papers set at the Matriculation Examination will form an astronomical gymnasium to students.

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D. B. KHARAS.

FORT AND PROPRIETARY HIGH SCHOOLS: *1st July* 1906

PREFACE TO THE SECOND EDITION.

THE favourable reception accorded to this book by the press and the teaching profession, as well as the fact that the Second Edition of it has been called forth within a few months of a reprint of the First Edition, may be regarded as an indication that it has supplied the want of a suitable text-book on Astronomy for Matriculation candidates, written in an easy intelligible way and well illustrated.

This edition has been carefully revised and enlarged, and the information brought upto date. The Introductory Chapter has been re-cast and expanded by the transference to it of the article on "the Phenomena of Diurnal Motion" from Chapter III and the introduction of one or two new points. A brief treatment has been given of "Standard Time" in Chapter XVI, and of "the Tides" and "Tidal Friction" in Chapter XVII. Reference has been made to "the Planetesimal Theory of Evolution" recently started in America. In short, important additions have been made in almost all chapters.

In the work of revision, Professor F. R. Moulton's recent book "Introduction to Astronomy" was found very useful and suggestive, besides the other standard authors consulted in the preparation of the first edition.

The necessity of printing the diagrams on separate pages no longer existing, they have been incorporated into the text in this edition. Twelve new illustrations have been added, and those of a comet and the Nebulæ of Orion and Andromeda have been replaced by others taken from recent photographs.

The Author acknowledges his obligations to several teachers for their valuable suggestions to extend the scope of usefulness of this manual. His thanks are also due to his assistant, Mr. Sadashiv Narayan Moghe, for having kindly looked over the proofs.

D. B. KHARAS.

FORT AND PROPRIETARY HIGH
SCHOOLS: *25th January* 1908.

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"The contemplation of celestial things will make a man both speak and think more sublimely and magnificently when he descends to human affairs."—*Cicero*.

"Contemplated as one grand whole, astronomy is the most beautiful monument of the human mind, the noblest record of its intelligence."—*La Place*.

Sir William R. Hamilton, the eminent mathematician, has called astronomy "man's golden chain between the earth and the visible heaven," by which we "learn the language and interpret the oracles of the Universe."

"The student of astronomy must expect his chief profit to be intellectual, in the widening of the range of thought and conception, in the pleasure attending the discovery of simple law working out the most complicated results, in the delight over the beauty and order revealed by the telescope and spectroscope in systems otherwise invisible, in the recognition of the essential unity of the material universe and of the kinship between his own mind and the Infinite Reason that formed all things and is immanent in them."—*Young*.

CHAPTER I.

INTRODUCTORY.

1. The word '*Astronomy*' is derived from two Greek words '*aster*,' a star, and '*nomos*,' a law or discourse. It is the science which deals with the heavenly bodies, their forms, dimensions, distances and motions (both apparent and real), the laws which regulate these motions, their constitution and the effects they produce upon each other by their attraction.

2. **Celestial Bodies.** The *Celestial* or *Heavenly Bodies* include the sun, the moon, stars, planets and their satellites, meteors, comets, the Milky Way, the nebulæ, and the Zodiacal Light.

The *Sun* and the *Moon* are bodies quite familiar to us.

The *Stars* are shining points of light which bespangle the sky. They are called '*fixed*,' because they do not change their *relative* positions from year to year.

Planets are certain star-like objects which shine with a steady light and *move* among the fixed stars; hence the name (from *planeta*, a wanderer). Our earth is one of them, as we shall learn later on.

Meteors (Gr., *meteoros*, raised high above the earth) are star-like points of light, which shoot across the sky and disappear in a few seconds. Hence they are otherwise called '*Shooting Stars*.'

Comets (Gr., *cometes*, hairy) are bright objects surrounded by a luminous fog and sometimes accompanied by a long tail of light. They are usually invisible to the naked eye.

Nebulæ (plural of *Nebula*, from Gr., *nephelé*, cloud, mist) are dim cloud-like patches of light seen among the stars. Only half a dozen are visible to the naked eye. They are at immense distances from us.

The *Milky Way* is a band of faint light seen on moonless nights, stretching from one horizon, almost overhead, to the

opposite horizon. It is otherwise called the *Galaxy*, and consists of an infinite number of stars packed together.

The *Zodiacal Light* is a slanting cone of light seen during the spring or autumn near the place where the sun rises or sets.

3. The Celestial Sphere. All these heavenly bodies appear to be situated on the inner surface of an immense blue hemispherical dome, which seems to rest on our earth. A similar dome but inverted, which might be supposed to be below the horizon, would complete a hollow sphere. This sphere is called the *Celestial Sphere* (or popularly, the "sky"), in the centre of which the earth seems to be placed. The ancients regarded it as a material structure, revolving once round the earth in 24 hours, and carrying the heavenly bodies with it. Astronomers have now discarded this view, because what appears to be the blue sky is due only to our atmosphere. If we could go beyond the atmosphere, we should see only the dark background of space with the celestial bodies shining on it. But still it is found convenient to study heavenly bodies as being projected on this fictitious celestial sphere, which is supposed to be *infinite*, *i.e.*, too great for human conception.

The *Sphere* is a solid body such that all points on its surface are equally distant from a certain point within it called the centre of the sphere.

The *Great Circles* of a sphere are those whose planes pass through its centre. They always divide the sphere into two equal parts.

The *Small Circles* of a sphere are those whose planes do not pass through its centre. They divide the sphere into two unequal parts.

There are various uses and meanings of the word 'Horizon'. The *Visible Horizon* (Gr., *horizo*, to bound) of a place is the line which bounds our view on all sides and where the earth and the sky appear to meet. On land it is generally an irregular and broken line; but on sea or in an extensive plain it is a true circle.

If a tangent plane be drawn through the observer's eye and produced indefinitely, it will cut the celestial sphere in a circle. This circle is called the *Sensible Horizon* of the observer. (Fig. 1.—NESW.) Its plane is perpendicular to

the plumb-line, the direction of which is called the *vertical.* When the word *horizon* alone is used in astronomy, the sensible horizon is meant.

The *Rational* or *Celestial Horizon* is a great circle of the celestial sphere, the plane of which passes through the *centre of the earth* and is parallel to the sensible horizon. (See Fig. 13.) Though the plane of the sensible horizon is 4,000 miles distant from the rational horizon, yet upon the infinite celestial sphere they coincide into one single great circle 90° from both the zenith and the nadir, since even a distance of 4,000 miles dwindles into insignificance compared with the vast extent of this sphere.

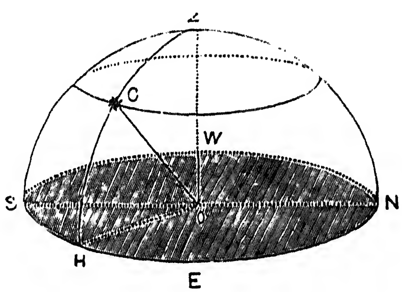

Fig. 1.—Horizon, Zenith, Meridian, etc.

O, the Observer's Place,
NESW, his Sensible Horizon.
N, E, S, W, the Cardinal Points.
Z, his Zenith.
NZS, Celestial Meridian.

Angle COH or arc CH, Altitude of the Object C.
Angle COZ or arc CZ, Zenith-distance of the Object C.
ZCH, Vertical Circle of the Object C.
Angle SZC or arc SWNEH, Azimuth of the Object C.

On the sensible horizon there are 4 chief points, North, East, South and West, called the *Cardinal Points*, at a distance of 90° from each other. (Fig. 1.—N, E, S, W.) The Cardinal Points can be roughly determined (1) by means of a compass, the magnetic needle of which points approximately north and south, or (2) by observing the position of the pole-star. Fig. 2 shows how we can determine the position of the pole-star by finding out the group of stars called the Grea

Bear or the Dipper. The stars β and a are called the "*the pointers.*" The pole-star is quite close to a point in the heavens called the North Pole, and apparently does not change its position, while other stars daily revolve round the Pole. The Dipper does the same, but in all positions of the pointers the line βa joining them is directed towards the pole-star and, therefore, to the Pole. Hence by simply producing this line to about five times its length, we can get at the pole-star, *i.e.*, at the Pole. If we imagine a point on the horizon immediately under the Pole, that point will be the *true north point.* The one directly opposite to it, *i.e.*, 180° from it, is the *true south.*

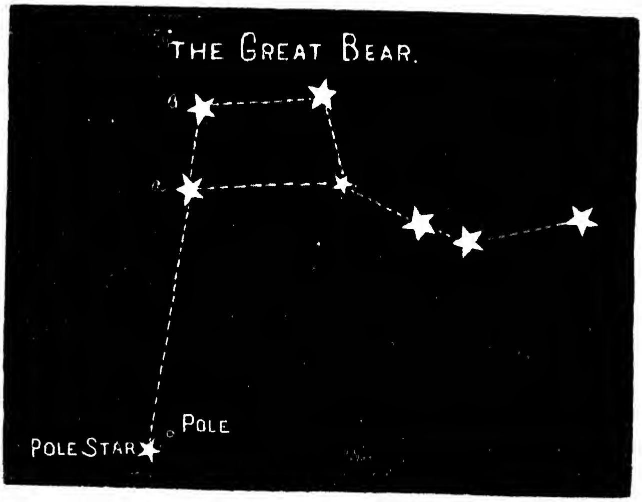

Fig. 2.—The Great Bear or the Dipper and the Pole-Star.

If the direction of the plumb-line be produced upwards to meet the sky, the point at which it cuts the celestial sphere overhead is called the *Zenith* of our place. (Fig. 1, Z.)

The point where the plumb-line produced downwards strikes the celestial sphere underfoot is called the *Nadir* of the place.

Celestial Meridian (Lat., *meridies*, midday) of a place is the circle cutting the horizon at the north and south points and passing

through the zenith. (Fig. 1—N Z S.) When a body comes to the meridian, it is said to *culminate*. Then it is at its greatest height above the horizon.

The *Vertical Circle* of a heavenly body is the circle drawn from the zenith to the nadir and passing through the body. (Fig. 1—ZCH.) Vertical circles are so called, because they are vertical to the horizon.

4. **How to find the true north-and-south line by the sun.** Erect a sharply-pointed vertical column on a horizontal stretch of ground in a position open to the sun's rays. The shadow cast by the column shortly after sunrise will be very long and towards the west, but will go on decreasing as the sun rises higher and higher, until, when it reaches the meridian, the shadow is the shortest. Then we have the *true noon*. After that the shadow falls eastward and increases in length till the sun sets.

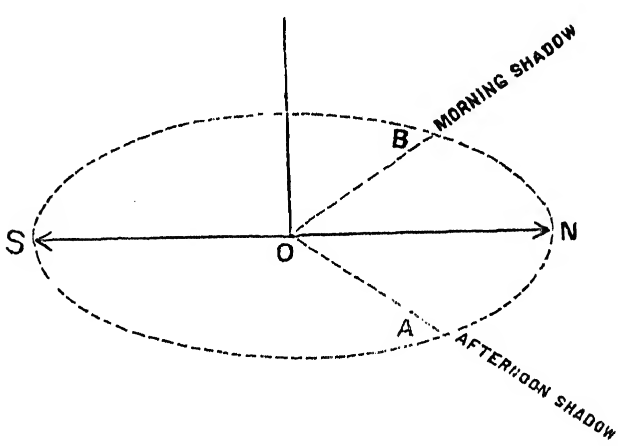

Fig. 3.—How to find the true north-and-south line.

Now draw the line OB on the ground along the length of the shadow some time before noon, and from the foot of the column as centre and this line as radius draw a circle (Fig. 3). Then you will notice that after noon one shadow will be of the

same length as the line previously marked, and its extremity will fall on the circumference of this circle. Draw the line OB along the length of that shadow as before. Bisect the angle AOB by the line ON. This line will point exactly *north and south*. Then, if you draw a straight line at right angles to ON, it will point to true *east and west*.

If we also mark the two times when the shadow of the same length is cast before and after noon and find the mean of these times, we can know the exact *time of the sun's meridian passage*.

In Fig. 3, as the shadows are shown falling *northward* of the column, the sun must be southward of it. However, if the sun's daily course be north of the zenith (as it is for a few months of the year in Bombay), the direction of the shadows will be *southward*.

15th May – 29th July

The sharply pointed column referred to above was used by the ancients under the name of '*Gnomon*' for this and other astronomical purposes. The obelisks of Egypt were probably built to serve as such gnomons.

5. **Constellations.** The stars, though they appear to be scattered about in the sky, may be grouped, such groups being called *Constellations*. The ancients gave them fanciful names, from the supposed resemblance of their forms to well-known animals or objects, such as Ursa Major (Fig. 2), Ursa Minor, Cassiopeia or the Lady's Chair (Fig. 4), Orion or the Hunter (Fig. 5), the Great Dog, the Southern Cross (Fig. 6) and others. The ancients knew of 48 constellations; 19 new have been formed by modern astronomers. The student should observe and be able to recognise some of these constellations.

It is remarkable that the constellations have kept the same forms in which the ancients observed them; in other words, the *relative* distances of the stars composing the constellations have not changed for thousands of years, so far as naked-eye observations are concerned. But this is not strictly true, as we shall see later on.

6. Phenomena of diurnal motion. We see the *sun* daily rising in the east, climbing up the sky, and setting in the west. After about 12 hours, it re-appears on the eastern horizon to once more complete its circuit of the sky. Its rising- and setting-points on the eastern and western horizons are, however, different at different times of the year, and its diurnal arcs are not the same in size at all seasons, but its paths at various seasons are all parallel to one another. The *moon* does the same, rising, culminating and setting, but presenting different appearances from day to day.

If we observe the *stars*, we find that they too have a daily motion, describing parallel arcs of different size in the sky, but all in the same time. These circles, however, are not vertical to the horizon at all places. (Figs. 35, 36, 38.) For example, in Bombay, these diurnal arcs are seen slanting towards the south (Fig. 36). Due north, there is a point in the sky which does not seem to take part in this daily motion of the heavens, and the celestial dome seems to turn round this point. This point is called the "*North Celestial Pole.*" In Bombay, it is about 19° above the horizon due north. In the southern sky there is another point which has also no motion. It is called the "*South Celestial Pole,*" but it is invisible in Bombay, being below the horizon. The position of the North Celestial Pole is fortunately marked by a star very close to it, called the *Pole-star* or *Polaris*. It does not rise or set, but it moves in so small a circle round the pole that it hardly seems to change its position, when seen with the naked eye. The altitude of this star in Bombay is about 19°. Its altitude at other places in the northern hemisphere depends upon the positions of such places; the farther a place is from the equator, the greater is its altitude. (*Cf.* Art. 11.) The pole-star is invisible in the southern hemisphere.

7. Daily motions of stars as seen in Bombay. The altitude of the pole-star in Bombay being 19°, we shall observe that stars which are within 19° of

it, like the 'Guards of the Bear,' will perform the whole of their small daily circles above the horizon in 24 hours, that is, they will not rise or set. These are called "*Circumpolar Stars.*" (Fig. 36.) If we begin observing such a star on the meridian when it is above the pole-star, we find it descending gradually towards the west, until after 6 hours it will begin to return towards the north. Then, if we could follow its path during the day-time, it would be seen after 6 hours more to be exactly due north. It will then continue to ascend backward from west to east, moving in 6 hours more as far east of the meridian as it was observed west of it. The remaining part of its circle will be performed in 6 hours more, when it will be seen in just the same position as at the time of the first observation, having described one small complete circle above the horizon in 24 hours. Circumpolar stars, therefore, can be seen north, east, south and west of the pole-star.

Suppose we now make a similar observation on stars more distant from the pole-star, for example, the Great Bear (Fig. 2). If we observe this constellation in February, it will be seen gradually rising from the east at about 7 P.M., and climbing up the sky with its 'tail' *below* its 'body,' but keeping the 'pointers' always in a line with the pole-star. After passing the meridian, it will begin to descend towards the west, with its tail now *above* the body, until it sets in the west. It will never be seen north of the pole-star, but it will describe the greater part of its daily circle above the horizon, and will be consequently more than 12 hours visible.

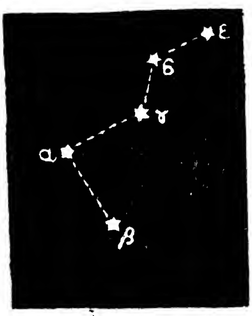

Fig. 4.—Cassiopeia or the Lady's Chair.

Another interesting constellation, Cassiopeia (or the Lady's Chair), should be observed. Its shape is roughly that of W (Fig. 4), and it is always seen on the side

of the pole opposite to the Great Bear, so that, when Cassiopeia is high up in the sky, the Great Bear is low down, and *vice versa*.

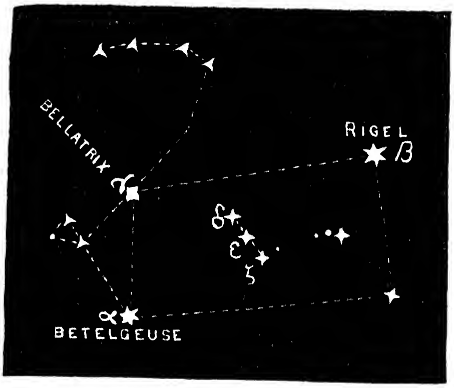

Fig. 5.—The Orion or the Hunter.

Let us now observe stars about 90°from the north celestial pole. For this purpose we shall choose the beautiful constellation of Orion (Fig. 5). When it is seen rising in November, its belt-stars, which are 90° from the pole, are found to rise due east, and the group itself ascends higher and higher, until, when it comes on the meridian, it is seen a little south of the zenith. It then slowly declines and sets due west, after remaining 12 hours above the horizon. Thus the diurnal circle described by Orion is slanting to the horizon towards the south.

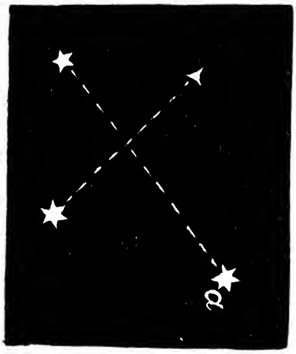

Fig. 6.—The Southern Cross.

Lastly, if we observe a constellation towards the south, like the Southern Cross (Fig. 6), we notice that it rises south of east, has a small part of its daily circle above the horizon, and sets south of west. It thus remains visible less than 12 hours above the horizon.

During all these observations we shall notice one thing, *viz.*, that the *distances* between the stars do not increase or diminish, but keep the same, in whatever part of the sky they may be. The aspect of the starry firmament, however, will be different

when viewed at different seasons, as will be noticed later on (Art. 22). The stars which we see, for example, in March will be quite different from those we observe in September. Thus the stars seem to have (1) a diurnal motion from east to west, and (2) an annual shift in the same direction.

As seen from other parts of the earth, the daily courses of stars will be different from those seen in Bombay. These we shall discuss in Chapter VI.

8. To find the true north celestial pole by circumpolar stars. We have seen that circumpolar stars do not rise or set, but describe circles round the north celestial pole, coming east, south, west and north of it. Thus in their daily courses they will cross the meridian twice, once when they are above the pole and next when they are below it. These two transits are called "*upper and lower culminations.*"

The pole-star, which is about $1\frac{1}{4}^{\circ}$ from the pole, also describes a small circle round it, and at its upper and lower culminations it will be in a true northerly direction. Thus, if we notice its highest and lowest positions and bisect the angle subtended by these two positions at the eye, we shall get the position of the *true north celestial pole.*

9. Angular measurement. The apparent distance of two objects from each other on the celestial sphere cannot be measured in feet or yards. It is measured in degrees ($^{\circ}$), minutes ($'$), and seconds ($''$). The circumference of a circle is divided into 360 equal parts called '*degrees*,' each degree into 60 equal parts called '*minutes*' and each minute into 60 equal parts called '*seconds*.' This sort of measurement is called *angular measurement*, and its unit is the *degree*. The distance between two stars on the celestial sphere is thus measured by computing the number of degrees in the angle subtended at the observer by the arc of the circle between the stars, or more commonly, the number of degrees in the *arc* itself, as it is more convenient to measure an arc than an angle on a spherical surface.

The angular height of a celestial object above the horizon, measured by the arc of the vertical circle passing through the object and intercepted between it and the horizon, is called the *Altitude* of the object. (Fig. 1—Angle COH or arc CH.)

The angular distance of a body from the zenith of a place, measured by the arc of its vertical circle intercepted between it and the zenith, is called its *Zenith-Distance.* (Fig. 1—Angle COZ or arc CZ.) It is evidently the complement of altitude. (Altitude+Zenith-distance=$90°$.)

When a body is on the *meridian*, its altitude is $90°$ and its Z.D. is $0°$. When it is on the *horizon*, its altitude is $0°$, and its Z.D. is $90°$.

CHAPTER II.

THE SHAPE AND SIZE OF THE EARTH.

10. At first sight the surface of the earth, where it is not obstructed by mountains or other high objects, appears to be *flat*, though it is really curved. This is because at one time we can see a very small portion of its surface, and in a small arc of a large circle we do not easily see a curve.

The earth is round like a ball, but not a perfect sphere. The results of certain measurements show that it is an oblate spheroid with its polar diameter (7,900 miles) 26 miles shorter than its equatorial diameter (7,926 miles).* (*Cf.* Art. 219.) The difference between the lengths of these diameters is called the *Polar Compression.* This difference is, however, so small compared with the large size of the earth that the earth may be said to be *almost spherical.*

11. Proofs of the earth's rotundity.

Important

(1.) Three-poles Proof.—Three poles, all of the same length, are placed at equal intervals AB, BC, (say each = 1 mile) in a lake or a canal in any part of the world. (Fig. 7.)

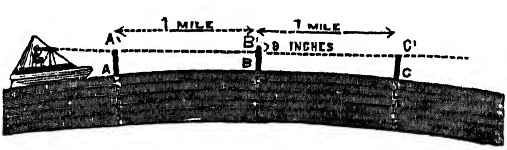

Fig. 7.—Three-poles Experiment (with Earth's surface *curved*).

Let the poles be AA′, BB′, CC′. Now if we place a telescope near A′, it is always observed that when A′ and C′ are seen in one line, B′ is seen about 8 inches above it, and when A′ and B′ are seen in one line, C′ is considerably below the line A′ B′. (Fig. 7.)

* More correctly, 7,899·582 miles and 7,926·592 miles respectively.

If the surface of the water be *flat*, A′B′C′ would be a straight line. (Fig. 8.)

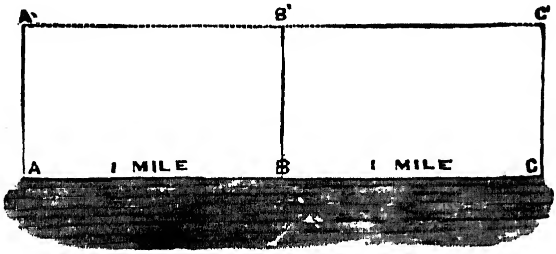

Fig. 8. Three-poles Experiment (with Earth's surface *flat*).

Hence we infer that the surface of the lake must really be curved down towards C, in other words the surface is convex or curved. As the same experiment carried out in different parts of the world shows the same result, we should conclude that the earth must be rounded everywhere.

To describe a circle having a curvature of 8 inches in one mile, the radius must be 3,960 miles, therefore the earth's diameter on this calculation must be 7,920 miles—a very fair approximation.

This experiment was first performed by Dr. Wallace in 1870 in a canal on Bedford Level, north of Ely.

Important (2.) **Ships and high objects on land.** When ships sail out of a harbour, we observe through a telescope that they sink *gradually* below the horizon, the hull first disappearing, then the funnels and the rigging, and lastly the top-masts. (Fig. 9.)

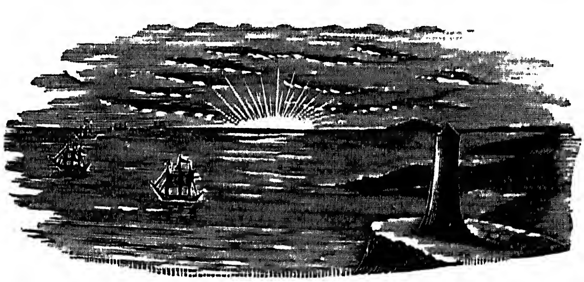

Fig. 9.—Aspects of a Ship putting out to sea or coming into port.

The same thing happens when ships come into the harbour. First we can see their masts, then their rigging and funnels, and lastly the hull. This is owing to the fact that the sea-surface is convexly curved, and this curvature *everywhere* hides

the lower parts of ships when their upper parts are visible. (Fig. 10.)

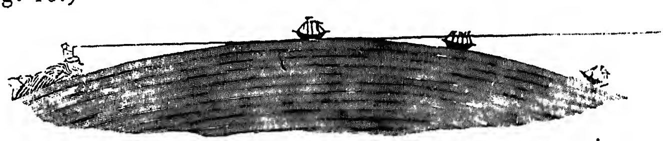

Fig. 10.—Curvature of Sea-surface.

If the sea-surface were flat, the tapering masts would first disappear, and then the bulky hull, and we should be able to see through a telescope the ships throughout their voyage. This never happens, which shows that the earth's surface is *curved* everywhere.

For the same reason, sailors, when sighting land, observe a similar phenomenon. They can first see the highest parts of buildings, such as pinnacles or tops of factory-chimneys, then gradually the lower parts.*

Similar appearances on land point to the globular shape of the earth. If we stand in the centre of a large plain, and observe high objects like mountains or towers situated at a great distance from us, we cannot see their bottoms. But, as we approach them, their heights apparently increase, and their bottoms become more and more visible. (Fig. 11.) This is

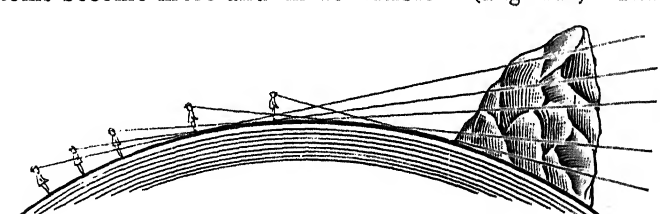

Fig. 11.—Apparent Increase in the Height of an Elevated Object as we approach it.

because the convex curvature of the land-surface between us and the objects hides their bases, and thus makes them look smaller in height than they really are. Since this phenomenon is observed in whatever directions we travel, the whole surface of the earth must be curved.

(3.) **Shape and extension of the horizon.** If we look at the horizon from a place where our view is unobstructed, it appears circular. The higher we go, the greater is its extent, but its shape still remains circular. (Fig. 12.) Now, whenever we observe the horizon, we look at a section of the earth, and these sections are always seen circular. But the only body, of which the sections are circular, whichever way they are made, is a sphere; therefore our earth must be a sphere.

If the earth's surface were flat, different elevations will produce no difference when the extension of the horizon.

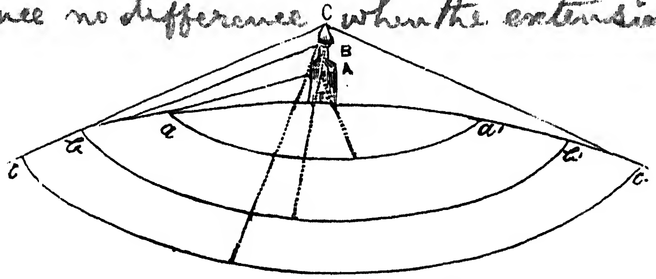

Fig. 12.—Shape and Extension of the Horizon.
Arcs aa', bb', cc' show extent of horizon from A, B, C respectively.

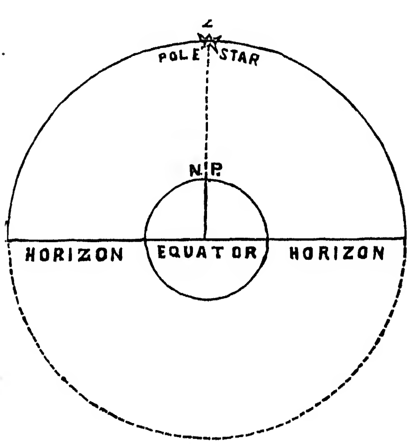

Fig. 13.—Altitude of the Pole-star at the North Pole.

Extent of horizon, in *miles* $= \sqrt{\frac{3}{2}h}$, where h = height of the observer in *feet* above the sea-level.

(4.) ***Pole-star argument.** If we go to the north pole, the pole-star would be seen at the zenith, *i.e.*, its altitude would be 90°. (Fig. 13.)

Travelling southwards from it, we should find that its altitude gradually diminishes, until, when we

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* This proof may be deferred till the student has read Chapter III.

reach the equator, it is seen just at the horizon, *i.e.*, its altitude is 0° (Figs. 14, 15.) *

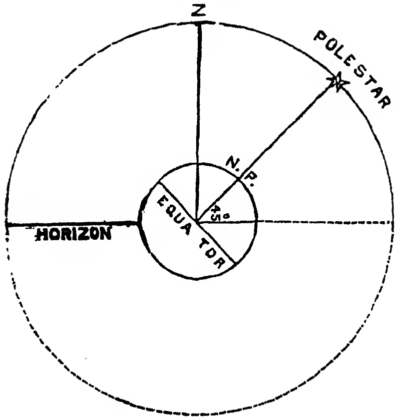


Fig. 14.—Altitude of the Pole-star at Latitude 45° N.

If we go south of the equator, the pole-star disappears, but other stars formerly invisible are now seen above our horizon. All these observations show that the surface of the earth is curved from *north to south*. Were the earth flat, the pole-star would appear at the *same* altitude at all places. In Fig. 16, the angles O1, O2, O3 between the lines pointing to the earth's pole-star and the surface would be all *equal* on the flat-earth theory.

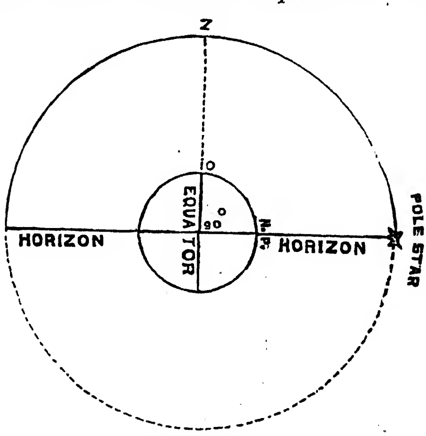


Fig. 15.—Altitude of the Pole-Star at the Equator.

The earth is also curved from east to west; if it were not, the sun would rise at different places at the *same* time, and local times would be everywhere just the same. Such, however, is not the case. For example, the sun rises earlier at places east of Bombay, and later at those west of it. (Cf. Art. 19.)

(5) **Circumnavigation.** Mariners like Magellan, Drake,
1520 1577-1580

* The horizon shown in Figs. 13, 14, 15 is the 'Rational Horizon' referred to in Art. 3.

Hawkins, Cook and others have circumnavigated the world by sailing continually as far as possible in one direction, *east or west*, without having come to any corner or edge. Besides this, the more they approached the poles, the shorter became their voyages, thus proving that the earth is round in *all* directions. If the earth were a cylinder, these voyages would be of equal length. The voyages could not be made north and south, because the polar regions are constantly frozen.

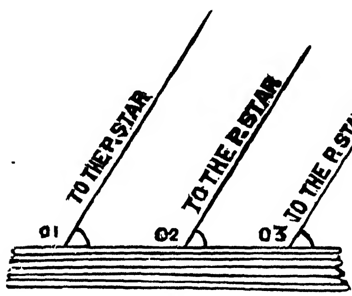


Fig. 16.—Altitude of the Pole-star on Flat-earth Theory.

(6) **Lunar eclipse.** (Compare the shadows cast by a cylinder a disc, a cone and a sphere.) When an eclipse of the moon occurs, the *outline* of the earth's shadow falling on the moon is always observed to be *circular.* The only body that *always* casts a circular shadow, whichever way it moves round a luminous body, is a sphere; therefore our earth must be a sphere. (Fig. 17.)

Fig. 17—Circular Outline of Earth's Shadow at a Lunar Eclipse.

(7.) **Reasoning by analogy.** All planets are observed through the telescope to be round. The earth is a planet; therefore it is probably round too.

12. **Size of the earth.** The earth is a very large body. If we observe a ship steaming out of the harbour, we shall continue to see it for about 7 miles before it sinks down out of sight; in other words, we command a horizon of seven-miles radius. The area enclosed in this horizon is about 154 sq. miles. Though by itself it is a large area, we fail to notice any sign of curve in it. Hence the earth's surface, of which it forms a part, must itself be large.

only a small

The highest mountain on the earth is about 5 miles high, and the deepest sea-bottom or valley about 5 miles deep. But in spite of these roughnesses, the earth is, comparatively, much smoother than an orange, because even the highest mountains and the deepest valleys are insignificant irregularities compared with the large size of the earth.

13. **Diameter, area, and volume of the earth.** The *mean diameter* of the earth is about 7,917 miles, and its *circumference* is 24,882 miles. Hence its *surface* is 197,000,000 square miles, and its *volume* is 260,000,000,000 cubic miles. The principles of the method by which the earth's diameter is found are explained in Art. 219.

$\pi = \frac{22}{7}$

$\pi r^2 =$ area of circle

Circumference of a sphere $= 2\pi r$,
Surface ,, ,, $= 4\pi r^2$,
Volume ,, ,, $= \frac{4}{3}\pi r^3$,
where $r =$ radius of the sphere.

CHAPTER III.

MOTIONS OF THE EARTH.

ROTATION OF THE EARTH.

14. The earth hangs in space like a balloon, apparently unsupported. But it is not at rest. We shall see in this chapter and the next that it has two motions, (1) it rotates on an imaginary axis, from west to east, *i. e.*, contra-clockwise, as viewed from a point above the northern hemisphere and (2) it revolves round the sun from west to east in an ellipse, having the sun in one of the foci.

Def.—A sphere is said to *rotate* when it turns round its centre, but the centre itself has no motion. All points on the surface of the sphere move round except two; these are called the "*poles*." The imaginary line joining them is called its "*axis*"

Def.—A sphere is said to *revolve* round another body when its *centre* turns round that body.

15. **Apparent daily motion of the heavenly bodies explained.** We have seen in Art. 6 how the sun, moon and stars seem to move daily in circles across the sky from east to west.

From these movements it appears as if the whole dome of the heavens is turning round the celestial poles once in 24 hours from east to west, carrying the sun, moon and stars with it. Now there are two possible explanations of this motion, (1) according to the ancient view, and (2) according to the modern theory.

Ancient view. To the ancients, the sun and the moon were small bodies and the stars mere points of light, compared with the large earth. They believed that the celestial sphere was a material structure, in which these heavenly bodies were fixed, and that this sphere *really* rotated round the earth about the celestial poles once in 24 hours. This belief was embodied in the Ptolemaic Theory (A. D. 130), which taught that the earth

was at rest in the centre of the Universe and that the sky revolved round it in 24 hours, carrying the heavenly bodies with it. This theory was considered so simple that it was believed in for 1400 years.

The ancient view examined. If, according to the ancient idea view, the celestial sphere really rotate round the earth once in 24 hours, the heavenly bodies should travel with tremendous velocities. The sun, whose distance from us is 93 millions of miles, must travel with a velocity of 6,800 miles a second, and the nearest star must move 17,600,000 miles per second to finish its daily round of the sky—a speed vastly greater than even the velocity of light! Hence it is not a reasonable theory that the whole sky should rotate round the earth in 24 hours.

velocity 76000

Modern view. The modern view is quite different. It was started by Nicholas Copernicus in 1543. He held that the earth was not fixed, but rotated on its axis in 24 hours from west to east, and that this motion caused the apparent daily rotation of the celestial sphere from east to west. In the light of our present knowledge that what we call the sky has in fact no existence, that the sun and the stars are enormously large bodies, and that the stars are at different and stupendous distances from us and from one another, this view is much simpler than the old one, and is now adopted by all astronomers. Besides, on this hypothesis all the celestial phenomena can be satisfactorily accounted for.

If the earth really turns on its axis, *how is it that we do not feel the motion?* We know by experience that when any motion is smooth and free from jerks or jar, we do not perceive it. So when the earth spins round on its axis without noise or jar, its inhabitants are unconscious of the motion, and are led to think that the earth is at rest and that the sky turns round. We have other examples of such illusory motion. (1) When we are in a passenger train, especially in a smoothly gliding electric car, which starts without jar or jerk, another train standing by appears to move, while ours seems motionless. (2) A person on the deck of a steamer slowly turning round in a harbour is under the impression that the objects on shore are moving round in the opposite direction. (3) A balloonist, as he rises higher and higher in the air, seems to think that the earth is falling down.

NICHOLAS COPERNICUS (1473-1543.)

16. Proofs of the rotation of the earth.

(1.) **Eastward Deviation of Falling Bodies.—Tower-and-Stone Experiment.** If a stone be let fall from the top of a high tower, it is observed that it falls at a point at the base of the tower *eastward* of the vertical line drawn from the place from which it is dropped, instead of falling in a *true* vertical line. This is because the earth turns on its axis from west to east; but the top of the tower, being at a greater distance from the centre of the earth than the bottom, moves with a greater eastward horizontal velocity than the base. The stone, being dropped from the top, takes up this greater velocity and falls *in advance*, to the *east* of the base. This proves that the earth on which the tower stands must be rotating from *west* to *east*. (Fig. 18.)

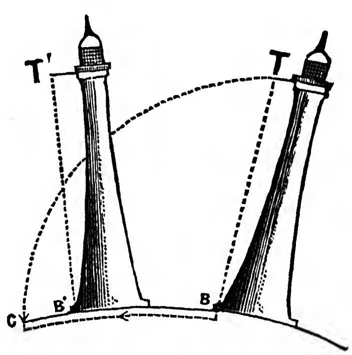


Fig. 18.—Tower-and-Stone Experiment.
T, B, first positions of top and bottom respectively.
T', B', second ,, ,, ,, ,,
C, actual position of the stone after Expt.

The experiment was first suggested by Newton, but was actually carried out first at Hamburg in 1802, then in 1831 in an abandoned mine in Saxony from a height of 520 feet, and was repeated 100 times. The average eastward deviation was found to be 1·12 inches.

(2.) **Foucault's Pendulum Experiment.** The rotation of the earth was proved experimentally also by Foucault in 1851. He suspended an iron ball weighing about 70 lbs.

by a fine wire more than 200 ft. long from the top of a high building in Paris, called the Pantheon, and placed below the ball a circular rail, on which was arranged a little ridge of sand. (Fig. 19.) The ball was first attached by a string to a point in one of the walls, and then the string was burnt. This let go the pendulum, which started swinging in a true plane. A needle, projecting below the ball, struck off at each oscillation of the pendulum a portion of the sand. Now it was noticed, after the pendulum had continued vibrating for a considerable length of time, that the needle did not strike the sand at the *same* points at different oscillations. In other words, the plane of the pendulum's swing did not appear to remain the same with respect to surrounding objects,

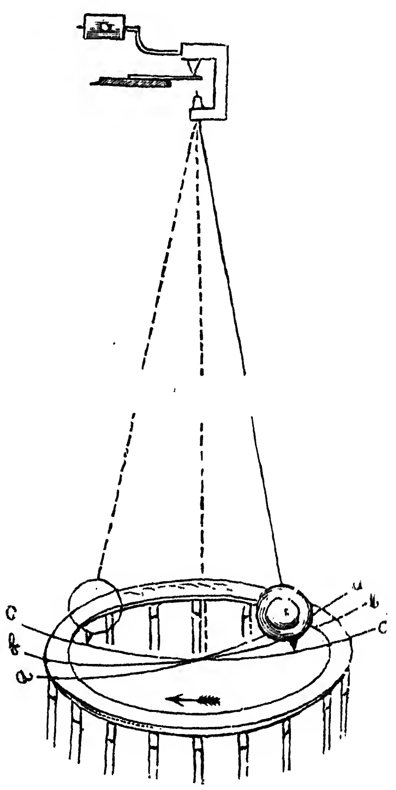


Fig. 19.—Foucault's Pendulum Experiment. Lines *aa'*, *bb'*, *cc'*, *dd'* show the successive positions of the plane of vibration.

but seemed to change slowly towards the right, *i.e.*, clockwise,* at each swing. Now this change in the plane of vibration might be (1) real or (2) apparent, caused by the actual turning of the table under the pendulum in the contrary direction-

* In the southern hemisphere it would shift contra-clockwise.

But the plane of vibration of a pendulum so suspended as to be equally free to swing in any plane never changes, even though the suspending point be twisted—a consequence of the property of *inertia.** Hence the different marks in the sand must have been made by the *rotation of the floor* under the pendulum, *i.e.*, *of the earth* itself, from right to left or contra-clockwise.† The arrow shows the direction in which the plane of vibration seems to change.

(3) **Shape of the earth.** The present shape of the earth itself is a proof of its rotation. A spherical plastic body, such as a thin flexible steel hoop, if rotated rapidly, has the tendency to bulge out at the middle and to flatten at the poles. Now there is ample testimony to show that our earth *was* once in a hot plastic state, and as it is bulged out at the equator and flattened at the poles, it must have been rotating on its axis.

There are some other dynamical proofs of the earth's rotation derived from (1) Foucault's experiments with the Gyroscope,
(2) Experiments on the deviation of projectiles and
(3) Observations of ocean-currents and trade-winds.
But they cannot be properly understood by beginners.

The sun, the moon and the planets have been observed to rotate on their axis. This makes it highly probable that our earth, which is a planet, also rotates.

17. Definitions. The *axis* of the earth is an imaginary line about which it rotates daily.

The two points on the earth's surface where the axis cuts the surface are called the *poles* of the earth. (Fig. 20.) These two points have no motion during the rotation of the earth.

The *Equator* is a great circle on the surface of the earth at equal distance from the two poles and having its plane at right

* Sir Isaac Newton enunciated three "Laws of Motion," of which the first is "Every body continues in its state of rest or of uniform motion in a straight line, except in so far as it may be compelled by force acting upon it to change that state." This property of matter is called *inertia.*

† This beautiful experiment is still shown to those who visit the Pantheon.

angles to the axis. It divides the earth's surface into two equal parts, the northern and southern hemispheres. (Fig. 20.)

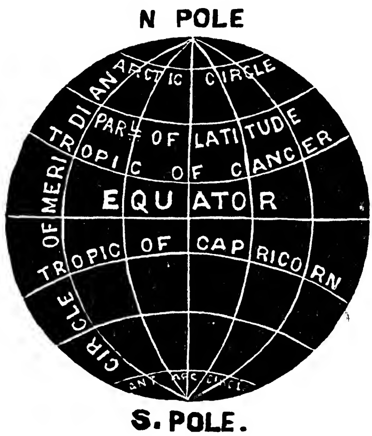


Fig. 20.—Illustrating Terrestrial Terms.

Parallels or *Circles of Latitude* are small circles parallel to the Equator. (Fig. 20.)

The angular distance of a place north or south of the equator is called the *latitude* of the place.

The two circles of latitude $23\frac{1}{2}°$ from the North and South Poles respectively are called the *Arctic Circle* and the *Antarctic Circle.* The two circles $23\frac{1}{2}°$ to the north and south of the equator respectively are termed the *Tropic of Cancer* and the *Tropic of Capricorn.* (Fig. 20.)

These circles divide the surface of the earth into five zones —the *Torrid Zone* between the two Tropics, the *North Temperate Zone* between the Arctic Circle and the Tropic of Cancer, the *South Temperate Zone* between the Antarctic Circle and the Tropic of Capricorn, the *North Frigid Zone* between the North Pole and the Arctic Circle, and the *South Frigid Zone* between the South Pole and the Antarctic Circle. (Fig. 20.)

Circles of Meridian are great circles passing through the poles and cutting the equator at right angles. (Fig 20.)

18. Velocity and plane of the earth's rotation. The circumference of the earth being about 25,000 miles, and its time of rotation about 24 hours,* the velocity of a point on the equator must be about 1,040 miles an hour. But it becomes less and less at points north and south of the equator. At the poles it is *nil.*

* The exact period is 23 hrs. 56 mis. 4 secs. (*Cf.* Art. 225.)

As the earth rotates, every point on its surface, except the poles, describes a circle. The plane of such a circle would be called the plane of rotation of the point. But the *standard plane of rotation* of the *earth as a whole* is the plane of rotation of a point on the equator. The plane of the equator, therefore, is the plane of rotation of the earth.

19. Day and night. In ordinary language, '*day*' is the interval between the rising and the setting of the sun, and '*night*' means the interval between the setting of the sun and its next rising.

Causes. The earth, not being a self-luminous body, shines by the borrowed light of the sun ; therefore, only one-half of the earth can be illuminated at a time. As the earth rotates on its axis from west to east, every place on its surface describes a circle daily, and is brought alternately in light and darkness. The time during which it is in light is called its *day*, and the interval during which it is in darkness is called its *night*. The imaginary circle which forms the boundary between the lit-up and dark hemispheres is called the '*Terminator.*' (Fig. 21, CA.)

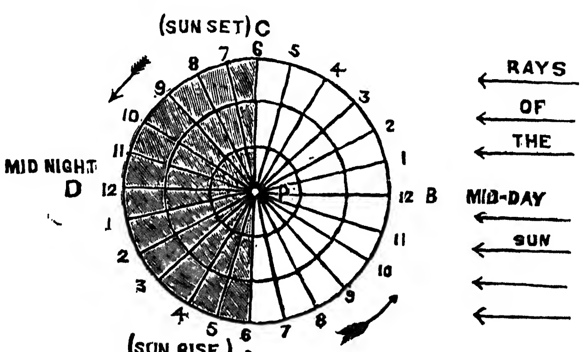


Fig. 21.—Day and Night.
ABCD represents the daily circle described by a place in 24 hours.

When a place enters the terminator at A, it is *sunrise* at that place. (Fig 21.) When the place has turned about 90°

from this and come to B, the sun is on the meridian, and it is *midday* or *noon*, and when, after turning about 90° more, it leaves the terminator at C, it is *sunset*. The remaining part of the circle is performed by the place in darkness or night, during which it comes to D at *midnight*. Finally it again enters the terminator at A.

Thus the rising and the setting of the sun are merely its apparent movements caused by the earth's rotation.

The apparent daily rotation of the stars may be similarly explained by the rotation of the earth.

20. Sunrise and sunset and local times at different places. As the earth rotates from west to east, at a place situated to the *east* of another, the sun rises and sets *earlier*. But a place to the *west* has its sunrise and sunset *later*. The time at every place being regulated by the movement of the sun, different places have different local times. (The numbers placed in a circle round the earth in Fig. 21 represent the hours indicating the local times of different places at the same instant.) For example, Bombay, being *east* of Greenwich, has its local time 4 hours 51 minutes *in advance of* Greenwich-time; but Bombay-time is one hour *behind* Calcutta-time, because Bombay is *west* of the latter place.

21. Effects of the earth's rotation summarised.

1. The apparent rotation of the heavenly dome from east to west in 24 hours.

2. Day and night.

3. The present shape of the earth (flattened at the poles and bulged out at the equator).

4. The trade-winds; the deviation of projectiles, in the northern hemisphere towards the right, in the southern hemisphere towards the left.

5. The eastward deviation of bodies falling from a great height.

CHAPTER IV.

ANNUAL REVOLUTION OF THE EARTH.

22. The sun's apparent annual motions.

Observations. (*a*) If we observe the sun at some place in the northern hemisphere on the 21st March, we shall find that it rises due east and sets due west, remaining exactly 12 hours above the horizon. From this date to about the 21st June it will be observed to rise more and more *north* of east, to set gradually further *north* of west and to be more than 12 hours above the horizon. Also during these 3 months the altitude of the sun at noon will gradually increase. From 21st June the rising and setting-points of the sun will recede more and more to the south point of the horizon, and its noon-altitude to diminish gradually, until about 22nd September, when we shall again see it rising due east and setting due west, and to be above the horizon for 12 hours. The southward movement and the diminution of altitude of the sun are continued, until on about 21s December it reaches its minimum altitude. Less During these 3 months it is less than 12 hours above the horizon. After this the places of rising and setting of the sun again come nearer and nearer the east and west points of the horizon, until on 21st March it again rises due east and sets due west.

These observations show that the sun apparently moves *northwards* towards the celestial pole from 21st December to 21st June and *southwards* from 21st June to 21st December again in the northern hemisphere. This is not, however, a real movement of the sun, but only an apparent motion due to a *change in the position of the earth* with respect to the sun.

(*b*) If the sun's apparent annual movement were only northwards and southwards, we should see the same stars on the meridian at the same hour each night during the year.

Such, however, is not the case. These annual changes of the sun with regard to an observer's horizon at different times of the year are associated with a *change in its situation among the stars*. If we observe a particular star, we find that it does not cross the meridian at the same time day after day. It comes on the meridian about 4 minutes earlier every day, so that at the end of a month it appears on the meridian 2 hours earlier than it did when first observed. The same is the case with other stars. The result is that different stars come to the meridian when observed at the same hour each night, and thus the aspect of the starry sky at different times of the year will be different, when observed at the *same* hour on each night. In fact, we shall notice that the stars seem to have all a constant change of position from *east to west*, finishing their round in the course of a year, because the same stars which at the time of our first observation were seen on the meridian will be again on the meridian at the same time after a year.

(*c*) Again, if we carefully mark day after day the point where the sun sets and also notice the stars which set after it, we shall find after a few evenings that these stars set earlier and earlier every day, until they are no longer visible to us after sunset. But other stars, which, a few days ago, were towards the east of the western horizon, are now seen near the sun; in other words, they are *getting continually nearer and nearer the sun*. This will go on for 365 days, when the same stars, which, at the time of our first observation, set immediately after the sun, will do so now once more at the same time, showing that they have completed a westward annual circuit in the heavens.

How explained. Observations *b* and *c* show that (1) either the stars move from east to west to meet the sun, or (2) that the sun moves backward among the stars from west to east, completing its round in a year. But as the stars, on account of their much greater distance from us than that of the sun, are practically stationary, we must conclude that the sun might be moving among the stars from west to east in the course of a

year. Repeated observations with instruments have shown that the sun follows the same path, year after year, in the sky. This path is called the *Ecliptic*, and is found to be a great circle of the celestial sphere.

Now this annual motion of the sun can be explained in two ways, (1) the sun might be revolving round the earth from

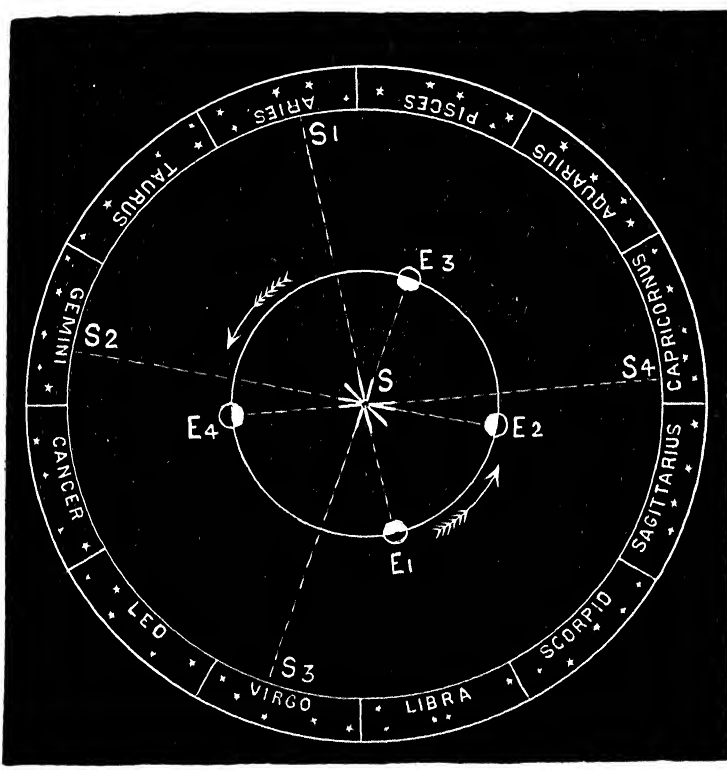


Fig. 22.—The Sun's Apparent Motion among the Stars.

west to east once in 365 days, or (2) the earth might be revolving round the sun in the same direction and in the same period, and causing the apparent annual motion of the sun in

the ecliptic from west to east. The former belief was held by the ancient astronomers for well nigh 1400 years, and is called the *Ptolemaic System* or *Geo-centric View*, but it is now discarded. The latter view was first put forth by Copernicus in 1543. It is called the *Copernican System* or *Helio-centric View*, and is now accepted by all astronomers, because all the complicated motions of the sun and the planets, that baffled ancient astronomers, can be easily and satisfactorily accounted for on this hypothesis; whereas the explanation given by the ancients was very complicated and difficult.

They thought the earth is in the centre.

Explained.

The apparent movement of the sun among the stars can be illustrated by Fig. 22, where $E_1E_2E_3E_4$ represents the earth's orbit round the sun, S, with the stars in the vast distance. When the earth is at E_1, we see the sun in the line E_1S_1 among the stars at S_1. As the earth moves from E_1 to E_2, the sun seems to move from S_1 to S_2 and to be projected against the stars at S_2. Similarly when we are carried with the earth to E_3 and E_4, the sun appears to shift its position slowly to S_3 and S_4, and when the earth again returns to its first position E_1 after a year, the sun is also seen having returned to the corresponding position S_1 and completed a circuit among the stars in a year. It is also clear from the figure that the direction of the sun's apparent motion is just the same as that of the earth's real movement, *viz.*, from west to east.

If the positions of the sun and the earth were interchanged, the same figure would explain how the sun would move among the stars on the Geo-centric Theory.

Thus we see that daily rotation is not the only motion of the earth. It also revolves round the sun once in 365 days at the rate of $18\frac{1}{2}$ miles a second. The exact period is, however, 365 days 6 hours 9 minutes 9 seconds, and is called the "*Sidereal Year*." If the earth only *rotated*, we should see the *same* groups of stars month after month during the year.

23. Proofs of the earth's revolution.

(1) Observations with delicate instruments have shown that stars are slightly but periodically displaced from their true positions. These apparent minute displacements, called the "*aberration of light*" and the "*annaul*

parallax of the stars," can be explained only by the revolution of the earth round the sun, and on no other hypothesis. But the proof is too difficult to be understood by beginners.

(2) The varying length of day and night and the consequent changes of seasons afford evidence of the revolution of the earth, because, to cause a variation in the duration of light and darkness, a change in the position of the earth is necessary (*Cf.* Art. 28 and Fig. 29).

(3). All the planets are observed to revolve round the sun. The fact that our earth is also a planet may, therefore, lead us to conclude that it also turns round the sun.

24. Shape of the earth's orbit. The path in space in which the earth revolves round the sun is called its *orbit.* If its plane were produced indefinitely, it would coincide on the sky with the plane of the ecliptic. Hence these two *planes* are just the same. But whatever the shape of the earth's orbit may be, the trace of its prolongation on the celestial sphere would be a circle, hence the shape of the ecliptic gives us no clue Idea as to the true form of the earth's orbit.

Careful measurements of the sun's apparent angular diameter taken at intervals of a few days show that it varies throughout the year. This means that the earth's distance from the sun also varies during this period. If the earth's orbit were a circle, with the sun in its centre, this distance should not vary. Evidently, therefore, the shape of the earth's orbit is some other closed curve.

The true form of the orbit of the earth can be determined as follows :—

Take a fixed point S to represent the sun. (Fig. 23.)

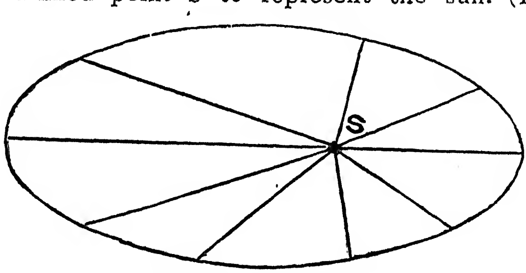


Fig. 23.—How to Determine the Shape of the Earth's Orbit.

Observe the angular diameter of the sun at noon, each day, and draw a series of lines from S to represent the earth's

distance from the sun on these days. As the distance varies inversely as this angular diameter, the lengths of these lines will be also inversely proportional to this diameter. The angles between them will be proportional to the observed distance which the sun moves among the stars along the sun. If we now draw a line passing through the extremities of these straight lines, we shall obtain an *ellipse*, which is the true shape of the earth's orbit.

The orbit of the earth is an ellipse, but the sun is in one of the foci. When the earth is at a point in its orbit corresponding to A′ in Fig. 24, (supposing the sun to be at F), it is said to be in *perihelion* (Gr. *peri*, about, and *helios*, the sun), because then it is *nearest* the sun. When the earth is at A, it is at its greatest distance from the sun, hence it is said to be in *aphelion* (Gr. *apo*, from, and *helios*, the sun). The earth comes to the perihelion in January, and to the aphelion in July.

25. The Ellipse. The Ellipse is a curve which may be drawn as follows :—

Stick two pins into paper, as at F and F′ in Fig. 24, throw a loop of a string over them, keeping the loop tight by means of a pencil, and let the pencil go round. Then it will mark out an ellipse.

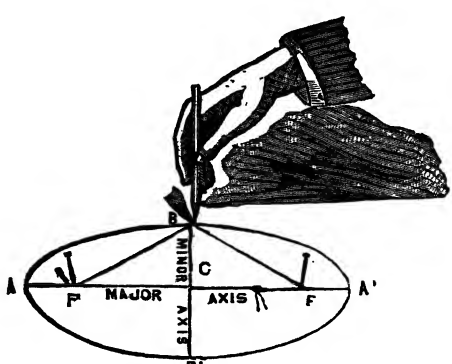


Fig. 24.—The Ellipse and how to draw it.

In Fig. 24, AB′A′B is the *ellipse*, F and F′ are called its *foci*, and C its *centre*. The length, AA′, of the ellipse, is called

its *major axis*, and AC its *semi-major axis*. BB′ is its *minor axis*. The fraction, $\frac{CF'}{AC}$ is called the *eccentricity* of the ellipse, and determines its *shape*. The essential property of the ellipse is that the *sum of the distances of any point on its circumference from the two foci is always constant*, and equal to the major axis of the ellipse, *i.e.*, BF′+BF=AA′. This quantity fixes the *size* of the ellipse.

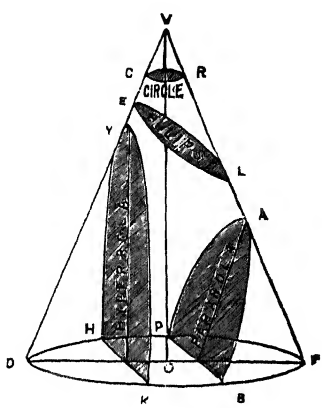


Fig. 25.—Conic Sections.

The ellipse is a 'conic section,' because when a cone is cut obliquely, the section is elliptical. In Fig. 25, the section EL is an ellipse.

CHAPTER V.

EFFECTS OF THE ROTATION AND REVOLUTION OF THE EARTH.

26. Axis of the earth. When the earth rotates and revolves round the sun, it does not keep its axis at right angles to the plane of revolution. Nor is the axis coincident with this plane. It is inclined to the plane of the ecliptic at an angle of $66\frac{1}{2}°$, so the angle between the plane of the equator and that of the ecliptic is $23\frac{1}{2}°$, and is called the *obliquity of the ecliptic*. This inclination has an important effect on the length of days and nights at different places on the earth, as we shall see in Art. 27. For example, in the northern hemisphere, from 22nd March to 21st September, the days are longer than the nights, and from 23rd September to 20th March the nights are longer than the days.

Again, while revolving round the sun, the earth keeps the direction of its axis unchanged, *i.e.*, keeps it pointing to the same star in its journey, *viz.*, the pole-star. The axis, therefore, remains *parallel to itself* in all parts of the earth's orbit. This property is called the *parallelism of the earth's axis*. Were it not for this fact, the earth's axis would point at *different* stars at different times of the year; in other words, there would be different pole-stars at different times.

As the earth moves spinning round the sun, all the positions of its axis, though parallel, when produced indefinitely, seem to meet the celestial sphere at *one single* point. This is because the sphere being *infinitely* distant from the observer, all these parallels, however far apart they may be, when seen by him, coalesce and pierce the celestial sphere at only one point—the "*vanishing point of perspective.*" Hence the north celestial pole is to be found in the same place among the stars during the whole journey of the earth round the sun.

27. Inequality of days and nights.

(*a*) If the axis of the earth were at right angles to the plane of the ecliptic, we should have equal days and nights at all places throughout the year, and, consequently, no change of seasons, because the terminator at any time would pass exactly

through the poles, and every place would perform exactly half its journey in light and half in darkness. (Fig. 26.) Another consequence would be that the sun would be always vertical at the equator. This is not, however, the case. The earth's axis therefore cannot be vertical to the plane of the ecliptic.

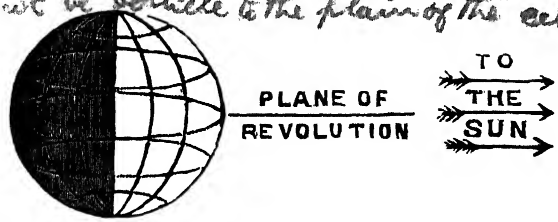


Fig. 26.—Axis of the Earth Vertical to the Plane of Revolution.

(*b*) If the axis were parallel to the plane of revolution, at least once in a year *all* places in the northern hemisphere would have 24 hours of day and no night. (Fig. 27.) But this never happens.

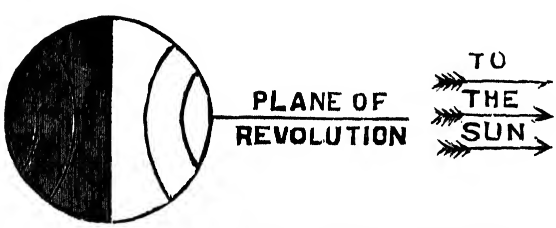


Fig. 27.—Axis of the Earth Parallel to the Plane of Revolution.

(*c*) But as the earth's axis is *inclined to the plane of the ecliptic*, days and nights are unequal at different times of the year. (Fig. 28.) From March 22nd to September 21st the north pole being turned towards the sun, at some places within the arctic circle the sun is continually visible for 24 hours of the day for some days. The sun, instead of setting in the west, goes round by north to east again above the horizon. (*Cf.* Art. 33.) At the same time, at some places within the antarctic circle the sun does not rise at all for some days, *i.e.*, there is a continuous night of 24 hours.

At the north pole there is a continuous day during these six months, and the south pole has an uninterrupted night of six months, since the earth's rotation does not bring the north pole within the region of darkness and the south pole within the region of light. (Fig. 28.)

Any place between the arctic circle and the equator will have longer days and shorter nights during the same period, as the greater part of its daily circle will have been turned in light.

At the equator, days and nights are of equal length all the year round, as the terminator exactly bisects the equator at any time.

On the other hand, during the same period nights will be longer than the days in the southern hemisphere.

As the earth's axis remains parallel to itself in its orbital revolution, this state of things will be reversed during the next six months. Then there will be short days and long nights in the northern hemisphere, and long days and short nights in the southern hemisphere. The north pole will have a night of 6 months' duration, and the south pole a continuous day of the same length.

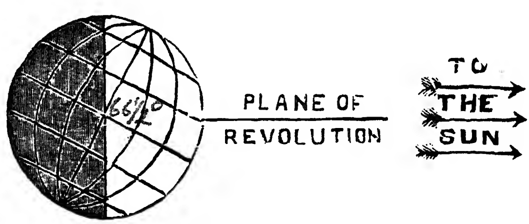


Fig. 28.—Axis of the Earth Inclined to the Plane of Revolution.

The inequality of days and nights is, therefore, the result of three causes :—

1. The inclination of the earth's axis to the plane of the ecliptic, as it rotates.
2. The parallelism of the earth's axis.
3. The revolution of the earth round the sun.

28. The seasons.

The periodic changes in climate in the course of a year are termed the *seasons*. They depend upon the prevailing temperature, which is influenced by (1) the inequality of days and nights and (2) the difference in the direction of solar rays. Both these result from the revolution of the earth round the sun, with its axis inclined to the plane of its orbit and remaining parallel to itself in its annual journey.

In summer, which commences on about 21st June in the northern hemisphere, as the north pole is turned *towards* the sun, the days are long and the nights short. The heat absorbed by the earth during the day is not all radiated during the short night, so day by day the heat accumulates, and the temperature rises. Besides, in summer the mid-day rays of the sun are less slanting in the northern hemisphere than in the southern, and are spread over a small area, therefore their heating effect is great. (Fig. 30.) At the same time, in the southern hemisphere the nights being longer than the days, and the solar rays being more slanting, the prevailing temperature will be lower than usual, and the season will be winter.

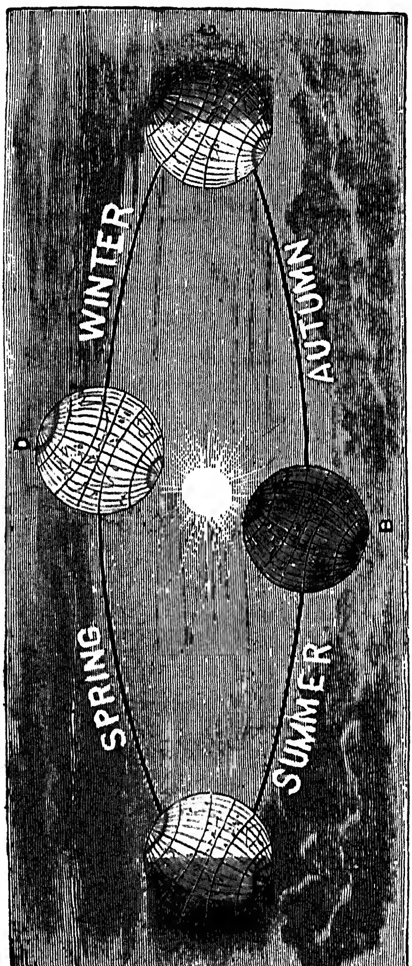


Fig. 29.—The Four Seasons.

In Fig. 29, A is the position of the earth in its orbit on about the 21st of June, and is called the *summer solstice*. On this date

the day is the longest and the night the shortest in the year. But from this time forwards the day will gradually shorten and the night lengthen.

Autumn. Three months after, about the 22nd of September, the earth is so situated in its orbit that the terminator passes exactly through the two poles, because then the axis is at right angles to the line joining the earth and the sun. Days and nights are, therefore, equal in all parts of the globe. The sun shining vertically at the equator, the temperature all over the world is neither very high nor very low. This will be the beginning of autumn in the northern hemisphere and spring in the southern hemisphere. In Fig. 29, B is the position of the earth then, and is called the *autumnal equinox* (Lat. *æquus*, equal, and *nox*, night). From 22nd September to 22nd December, days will become shorter and shorter, till, on the latter date, the night will be the longest in the year.

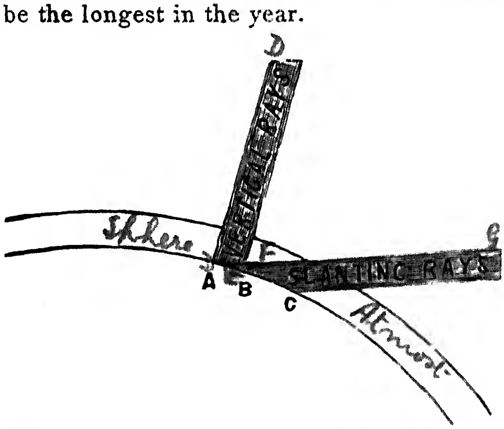


Fig. 30.—Effects of Vertical and Slanting Rays.
A B, the area on which *vertical* rays fall.
A C, ,, ,, ,, ,, *slanting* ,, ,,

Winter. After three months more, say, about the 22nd of December, when the earth has finished half a turn round the sun, the north pole is turned *away* from the sun, owing to the parallelism of the earth's axis. This marks the beginning of winter in the northern hemisphere with short days and long

nights. The time for radiating the heat being longer than the time for absorbing the solar heat, the temperature gradually falls. Besides, the direction of midday solar rays is *more slanting* than in summer. Now slanting rays, being spread over a greater area, diminish the effect of the heat. Also oblique rays have to pass through a greater thickness of our atmosphere, which absorbs a good deal of heat and diminishes their heating effect. (Fig. 30.) The corresponding season in the southern hemisphere will be summer, as the south pole is turned towards the sun. C in Fig. 29 is the position of the earth in its orbit on 22nd December, and is called the '*winter solstice.*'

Spring. About three months later, on the 21st of March, the earth is so placed that the terminator again passes through the poles, so days and nights are equal all over the globe, and the temperature is medium. Spring commences in the northern hemisphere and lasts till 20th June. Nature having been refreshed by her winter sleep, spring is the time of buds and leaves. At the same time, the southern hemisphere has its autumn. The position of the earth on 21st March is D (Fig. 29), and is termed the '*vernal equinox.*' In three months more, the earth again comes to the summer solstice.

At the equator the days and nights are equal, and the sun's rays come down almost vertically at noon all the year round, so there are no seasons in that part of the earth.

The recurrence of the same seasons after the lapse of 365 days very probably suggested to the ancients the idea of the *year.*

29. Appearance of the earth as seen from the sun at different times of the year.—Figs. 31, 32, 33, 34 represent the appearance of the earth as seen from the sun at the Summer Solstice, the Autumnal Equinox, the Winter Solstice and the Vernal Equinox respectively.

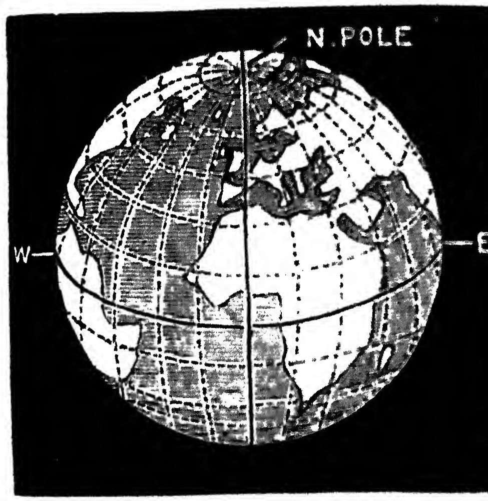


Fig. 31.—The Earth, as seen from the Sun at the Summer Solstice.

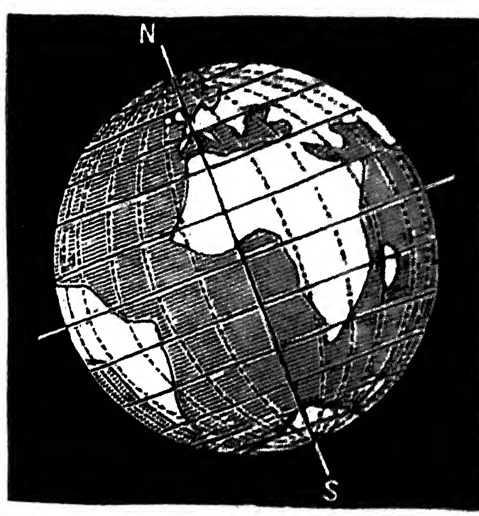


Fig. 32.—The Earth, as seen from the Sun at the Autumnal Equinox.

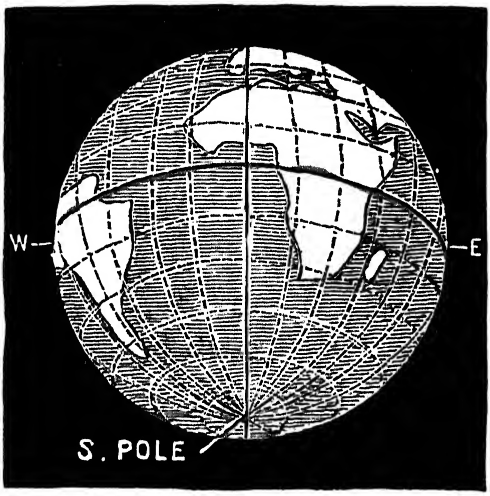


Fig. 33.—The Earth, as seen from the Sun at the Winter Solstice.

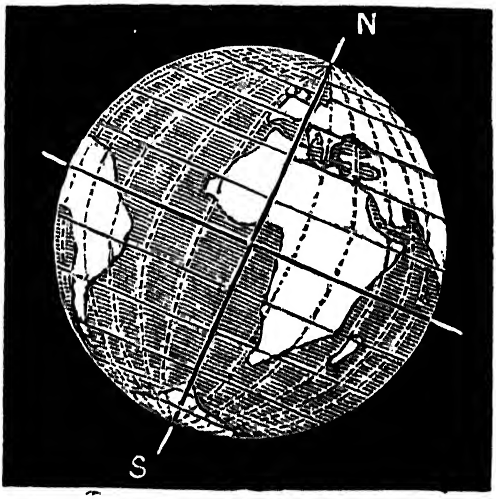


Fig. 34.—The Earth, as seen from the Sun at the Vernal Equinox.

30. The Zones.

The division of the earth's surface into 5 Zones referred to in Art. 17 has been made according to the climate prevailing in each during the year. In the *Torrid Zone*, though there is not great difference between the lengths of days and nights, still, as the solar rays can fall vertically some time in the year, the prevailing temperature is intensely hot. On the other hand, in the *Frigid Zones* the day is sometimes as long as 24 hours; but as these regions receive the most slanting rays, their heating power is almost neutralized, hence the bitterest cold prevails in these two zones.

Destroy

The *Temperate Zones* receive neither vertical nor very slanting rays; therefore the temperature there is mild,—neither very hot nor very cold.

31. Consequences of the earth's revolution summarised.

1. The apparent annual motion of the sun among the stars from west to east, and the consequent apparent change in the positions of the stars from east to west throughout the year.

2. The seasons.

3. Aberration of light.

4. The annual parallax of the stars.

Besides rotation and revolution, the earth has two other motions. (1) A slow wobbling movement of its axis causing the "Precession of the Equinoxes." (*Cf.* Art. 222) (2) A forward motion in space with the whole solar system towards the constellation of Lyra. (*Cf.* Art. 188.)

CHAPTER VI.

APPARENT DAILY MOVEMENTS OF THE STARS AND THE SUN AS SEEN FROM DIFFERENT PARTS OF THE EARTH.

32. **Altitude of the pole-star.** We have seen in Art. 11 that the height of the pole-star or the north celestial pole *at different places is different.* It increases as we approach the north pole, and decreases as we near the equator.* The movements of the heavenly bodies will, therefore, vary in different parts of the earth, because everywhere the line joining the centres of their diurnal circles passes through the pole-star; so these circles will not be inclined at the same angle to the horizon at all places.

33. **Daily motion of the heavens as seen from the north pole.**

To an observer on the north pole, the pole-star will appear

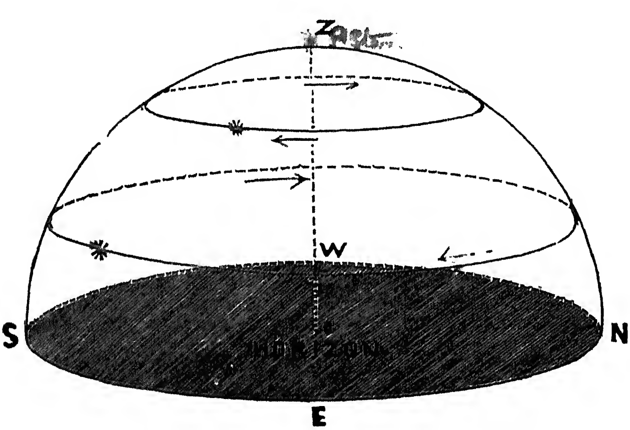


Fig. 35.—Daily Motions of the Stars as seen from the North Pole.

on the zenith. The stars will all travel in circles round the pole-star, parallel to the horizon. (Fig. 35.) They will not rise

* *The altitude of the pole-star at a place is equal to the latitude of the place.* For a geometrical proof of this theorem, the student is referred to Art. 209.

will increase as the latitude increases, and (4) other stars will rise and set in oblique circles similar to those in Fig. 36, making, however, different angles with the horizon at different stations.

35. Daily movement of the heavens as seen from the equator.

The observer on the equator would see the pole-star just on the northern part of the horizon; hence there are no circumpolar stars. The equinoctial will be a vertical circle. All the stars perform their journeys in arcs which are semicircles *vertical to the horizon*, and are consequently 12 hours above, and 12 hours below it. (Fig. 37.) The day and night will always be of equal length. To an observer at the

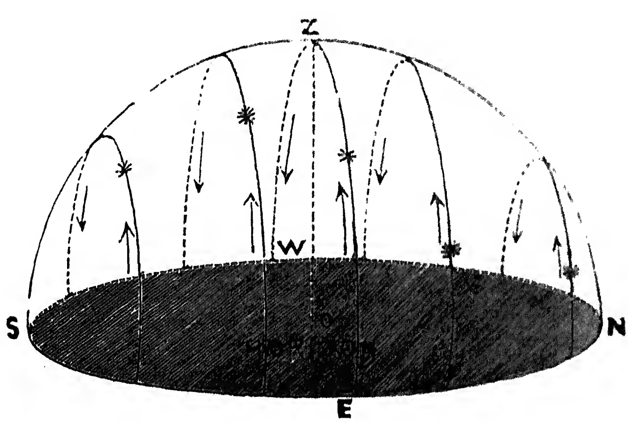


Fig. 37.—Daily Motions of the Stars as seen from the Equator.

equator *all* the stars in the heavens will be visible at some time during 24 hours.

36. Daily motions of the heavenly bodies as seen in Melbourne (in the Southern Hemisphere).

An observer in Melbourne (38° south latitude) will not see the north pole-star, as it is invisible in the southern hemisphere. There is no prominent star to mark the position of the

slanting towards the north, the line joining their centres passing through this point. (Fig. 38.) If the observer faces the south celestial pole, the direction of their motion will be, not

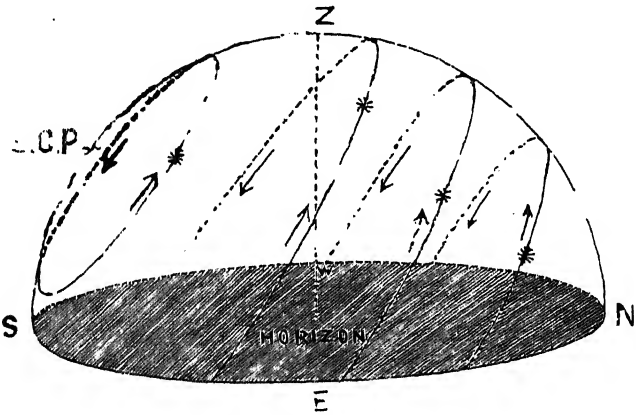


Fig. 38.—Daily Motions of the Stars as seen from Melbourne (Australia).

as in Bombay from right to left, but from left to right. Stars within 38° of the south celestial pole will not rise or set, but will go round this point continuously above the horizon. These are the *southern circumpolar stars*. Other stars will be seen describing arcs of circles parallel to the paths of the circumpolar stars.

CHAPTER VII.

THE MOON.

37. Size and shape. The moon is the most conspicuous of all the heavenly bodies, except the sun. But its conspicuousness is owing solely to its nearness to us: really it is very small compared with planets and stars. Its diameter is about 2163 miles, so its volume is only $\frac{1}{49}$ that of the earth. The moon's diameter can be determined by the method described in Art. 99.

As far as known, the moon's diameter is the same in all directions; that is, the moon is spherical.

38. Revolution round the earth. If we observe the moon for a few successive evenings, we shall find that it changes its position among the stars, day after day, towards the *east*. After $27\frac{1}{3}$ days it will be seen again in its first position. This is because it *revolves round the earth* in this period *from west to east*, accompanying the earth in its journey round the sun.

The moon's apparent daily movement from east to west is simply due to the rotation of the earth from west to east.

39. Orbit and distance. The moon's angular diameter has been observed to vary during its period of revolution. This means that its distance from the earth also varies. From this fact it has been determined that the shape of the moon's orbit is elliptical, the earth being in one of the foci. It is inclined 5° 8′ to the plane of the ecliptic. The two points where it cuts the ecliptic are called the *nodes*. The point in the moon's orbit where it is nearest the earth is called *perigee*; when it is at its farthest distance from the earth, it is said to be in '*apogee*.'

The mean distance of the moon from the earth is 238,840 miles. It is determined by the method described in Art 224.

about 51 minutes later every day. But the amount of daily retardation ranges from 38 minutes to 66 minutes, on account of the variation in the moon's motion. If the moon rises at 6 P.M. on a particular day, the next day it will not be seen on the horizon at the same time, because it has moved eastward during the preceding 24 hours. Therefore the earth, which rotates from west to east, will have to turn a little more on its axis to be able to see the moon rising again, and this additional turning will require about 51 minutes more.

As the moon revolves round the earth in $27\frac{1}{3}$ days, in one day it moves eastward, on an average, about $13\frac{1}{8}^\circ$. Therefore, the earth must turn $13\frac{1}{8}^\circ$ more to come into the same position with respect to the moon as on the previous day. So

$$360^\circ : 13\tfrac{1}{8}^\circ :: 24\times 60 \text{ mis.} : x \text{ mis., which gives } x = 51 \text{ mis.}$$

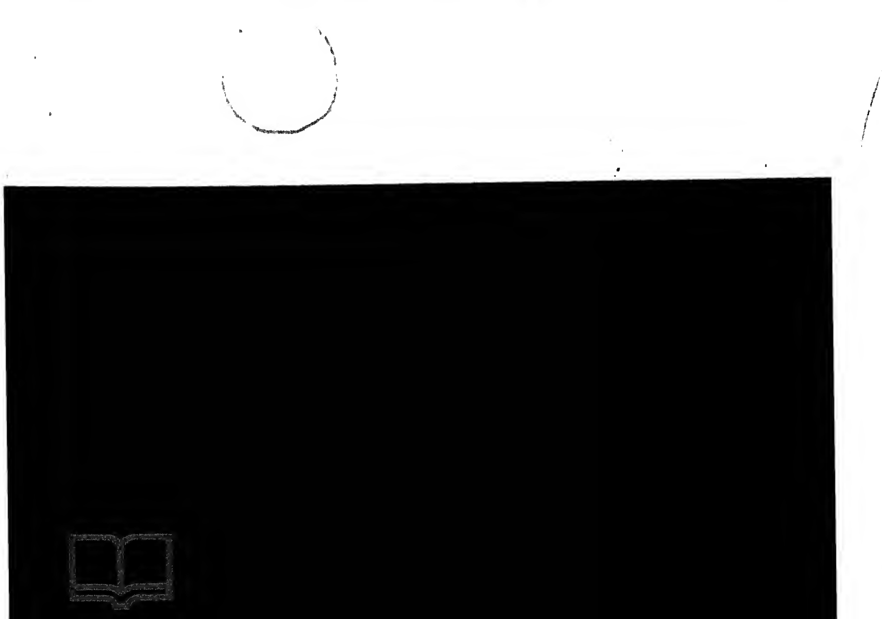
That is, the amount of the moon's average daily retardation is 51 minutes.

41. Phases of the moon. One consequence of the moon's revolution round the earth is that it changes its appearance, from day to day, in the course of a month. The changes in the moon's shape in the course of a month, as seen from the earth, are called the *Phases of the Moon*.

Cause. The moon, being a cold spherical body, shines by the reflected light of the sun, so only half of it is illuminated at a time. While it revolves round the earth, its illuminated hemisphere is *not always fully* turned towards the earth, so we cannot see the whole lit-up side at all times ; that portion of it can only be seen which is turned both towards us and the sun. Therefore, we sometimes see a crescent, sometimes a half, and at others the whole.

In Fig. 39, the inner circle represents the appearance of the moon to a spectator, not on the earth, but to one outside above the plane of the moon's orbit.

When the moon is at A in *conjunction*, *i.e.*, between the earth and the sun, we cannot see anything of it, as its dark side



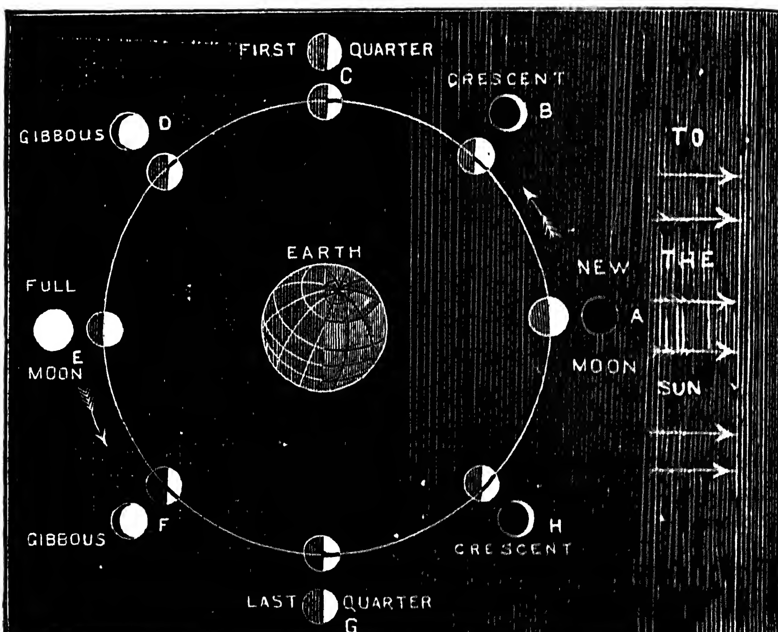
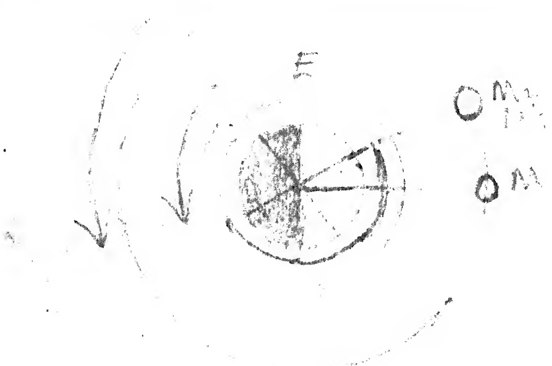


Fig. 39.—Phases of the Moon.



is turned towards us. Then we have *New Moon* (the astronomer's). Two or three days after, when it comes to B, it appears like a *crescent*, with its cusps turned away from the sun. After four days more, when it comes at C, half of the lit-up hemisphere is visible to us, and the moon is said to be in its *First Quarter or Quadrature* (Lat. *Quadrus*, square). About three days after this, it appears *Gibbous* (hump-backed) at D, when three-fourths of its illuminated disc is seen. Lastly, after 15 days from the commencement, when it comes in *opposition* to E, it is *Full*, because the whole of its illuminated hemisphere is turned both towards us and the sun. After this period, its appearance again changes, it becomes less and less, until after about $29\frac{1}{2}$ days from the beginning, it is again *New*, having passed through the same phases, but in a reverse order.

From A to E the moon is said to "*wax*," and from E to A back it is said to "*wane*."

42. Earth-shine. During the crescent phase, the unilluminated part of the moon shines with a dull leaden-coloured light. This is because the sun-light, falling upon the earth, is reflected by it, and thrown upon that side of the moon which is turned towards the earth. The dark portion of the moon is, therefore, illuminated by "*earthshine*." This appearance is popularly called "*the old moon in the new moon's arms*."

43. Sidereal and Synodic Months. The time taken by the moon to revolve round the earth must have suggested to the ancients the idea of the '*month*,'—a longer unit of time than the day.

A *Sidereal Month* (Lat. *sidus*, a star) is the time that elapses between the moon leaving a certain star and returning to the same star. It consists of $27\frac{1}{3}$ days.

A *Synodic Month* (Gr. *syn*, with, and *hodos*, way) or *Lunation* is the interval of time between two phases of the same kind, *e.g.*, between new moon and new moon, or between full moon and full moon. It consists of a little more than $29\frac{1}{2}$ days. It is otherwise called *Lunar Month*.

Why should these two periods be different ? The difference arises from the revolution of the *earth* round the sun during $27\frac{1}{3}$ days. Suppose, in a particular month, the earth, the moon, and the sun are in the positions E, M, S, respectively, and the moon, the sun and a star are on the meridian together at a place, when the moon is new. (Fig. 40.) After $27\frac{1}{3}$ days, the earth will have moved about 27° in its orbit to E′, and the moon, having finished one revolution round the earth from west to east, will return to the same *relative* position

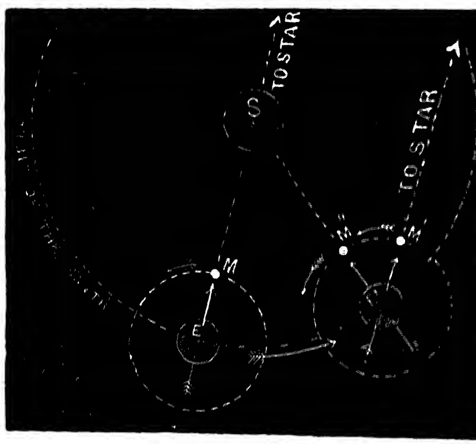


Fig. 40.—Sidereal and Synodic Months.

M′ with reference to the star, and a sidereal month will have been completed. But it is not yet new, as it is not in conjunction; therefore the moon has still to move a part of its *second* round to M″, to come in conjunction and be new again, and this takes two days more. Thus the interval between new moon and new moon will be more than $27\frac{1}{3}$ days, and, therefore, a synodic month is longer than a sidereal month.

For our ordinary purposes, we divide the year into 12 months, called *Calendar Months*, consisting of an arbitrary number of days, 30, 31, or 28.

44. Moon, not a self-luminous body. The phases of the moon prove that it is not a self-luminous body. It shines by the reflected light of the sun. Moon-light is, therefore, the same in character as sun-light.

45. Rotation of the moon.

Illustrations.

(*a*) Suppose a boy stands facing north. If he then turns round on his feet, he will successively face the other three directions, east, south, and west, before he again faces north. Thus a boy *rotating on his axis cannot face one and the same direction.*

(*b*) A boy facing north begins to walk round a table, but, while doing so, keeps facing the same direction (*viz.*, north). He cannot be said to have *rotated* on his axis, though he has *revolved* round the table, since he has not faced four different directions (illustration *a*). Besides, if there is another boy on the table, facing, say, south, he will be able to see successively the face, one side, the back and the other side of the revolving boy, *i.e. different* parts of his body.

(*c*) If the boy faces successively north, east, south, and west once during his circuit round the table, he *rotates* on his axis (illustration *a*) *as well as revolves* round the table *in the same time* (Fig. 41). Also, in this case, the boy

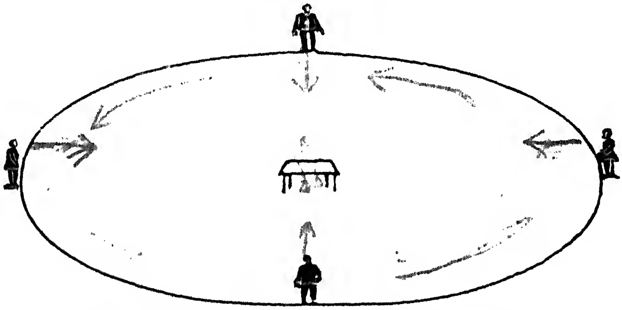


Fig. 41.—A Boy Rotating and Revolving Round a Table in the *Same* Time.

on the table can see *only his face* during his whole revolution. Thus the revolving boy can present his face, all throughout, to the one sitting on the table only when he rotates on his axis in the same time that he takes to walk round the table.

If we mark a conspicuous spot on the disc of the moon in a certain position, say, on the western edge, then, whatever be the subsequent phase, the spot will be seen in the same position on the disc as when first observed. From this we can say that the moon keeps the same half of its surface turned towards us ; in other words, *the moon always presents the same face to the earth.*

The reason of this is clear from illustration *c* given above, *viz.*, that *the moon rotates on its axis in the same time that it takes to revolve round the earth*—27⅓ days. Fig. 42 also illustrates this :—

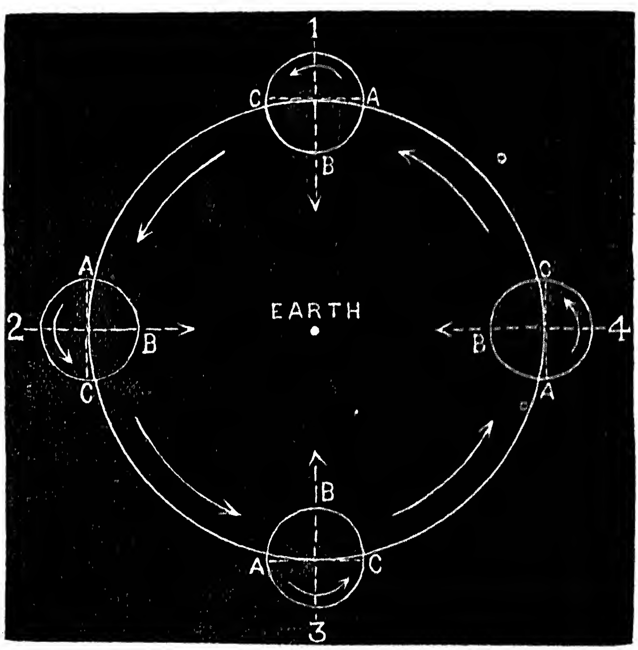


Fig. 42.—Why the Moon presents the Same Face to the Earth.

The figures 1, 2, 3, 4 represent the successive positions of the moon in its orbit. ABC is the moon's hemisphere turned towards the earth, of which B is the centre. Starting from

and a quarter of a rotation has also been made. When the moon comes to the position 3, half the journey has been performed, and also half a rotation, B still facing E. Similarly at 4, three-quarters of a revolution as well as three-quarters of a rotation have been made, and finally, when the moon returns to 1, it has performed a whole revolution and a whole rotation in the same time, and all throughout this period it has *presented the same face*, ABC, to the earth.

If the moon did not rotate on its axis, it would show *different* parts of its surface to us, as it journeyed round the earth, as is clear from illustration *b*.

If the moon rotates on its axis in $27\frac{1}{3}$ days, its day must consist of $27\frac{1}{3}$ of our days; therefore, for about 14 days one hemisphere must be in constant light, and the other must be in continual darkness for an equal interval. Its surface must, consequently, be exposed at one time to extreme heat, and at another time to the bitterest cold. Animal life, under these circumstances, must be impossible.

As the moon shows the same face to the earth, we cannot see its other side. However, owing to certain causes, small periodical changes occur in the position of the moon's surface as seen from the earth; consequently, sometimes we also see a little of the other half of its surface. These changes are called *librations*. About 59 per cent. of the moon's surface is thus visible to us.

46. Moon's motions summarised.

The *real motions* of the moon are :—

(1) Its revolution round the earth in a month.

(2) Its rotation on its axis in the same period.

(3) Its revolution round the sun as an attendant of the earth.

The *apparent motions* of the moon are :—

(1) Its daily round of the sky from east to west, as a result of the earth's rotation.

(2) Its shifting among the stars, from day to day, towards the east on account of its revolution round the earth.

47. Mass and Density. The *mass* of a body is the quantity of matter contained in it, *i.e.*, the number of tons or lbs. of material which it contains.

The *density* of a body is the weight of that body compared with the weight of an equal bulk of another body taken as the standard. In the case of the sun, the moon and the planets, this standard body is the earth. The density of the earth itself compared with water is 5.5. The density of a body is $= \dfrac{\text{its mass}}{\text{its volume}}$.

The mass of the moon is about $\frac{1}{81}$ that of the earth. The mass of a heavenly body is determined by its attraction for some other body. (*Cf.* Art 217.)

The density of the moon is about $\frac{3}{5}$ that of the earth, that is, the moon is made of lighter materials than the earth.

48. Superficial gravity. The superficial gravity, or the attraction of the moon for bodies on its surface, is only $\frac{1}{6}$ that at the surface of the earth, *i.e.*, a body, weighing 6 lbs. on the earth's surface, would weigh only 1 lb. on the moon in a spring balance.

49. Physical features. Even to the naked eye, the moon's surface appears diversified with dark spots of irregular shape. "Most people see a strong resemblance to a human face." When viewed through a telescope, the moon's surface appears extremely broken.* It is almost completely covered

* The best time to observe the moon through a telescope is a little before or after it is half.

with craters, mountain-chains, plains, rills, clefts and 'rays.' (Fig. 43.) Many of these have received names. Excellent photographs have also been taken of the moon's surface.

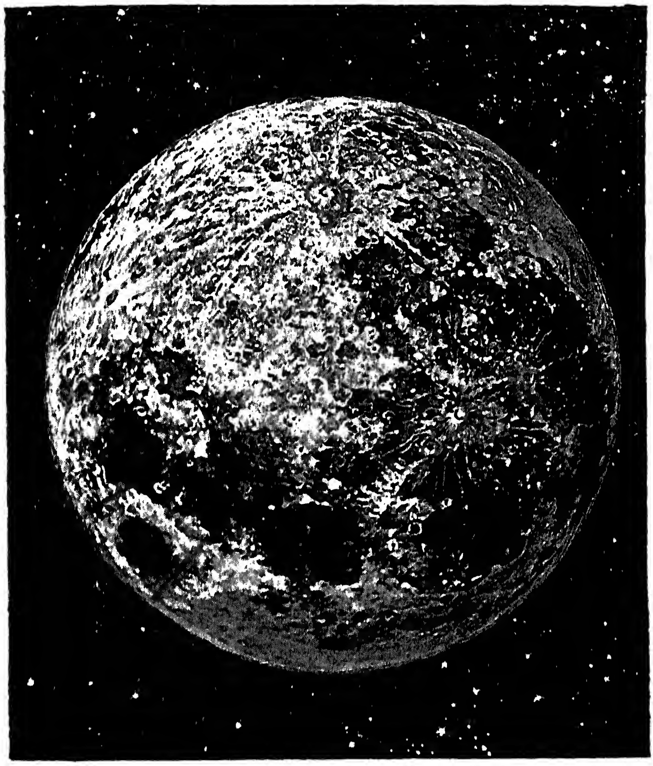


Fig. 43.—The Moon.

Craters The craters, which look like ring-shaped mountains, thickly bestrew the brighter portion of the moon. Some of them are of enormous size, being over 100 miles in diameter. In fact, they may be regarded as large circular plains surrounded by high walls—often 20,000 feet high—not unlike circus rings in appearance. Usually a conical peak is

found in the centre of the crater. (Fig. 44.) The craters are the moon's volcanoes, which might have been once active, but are now extinct. The chief craters are named Copernicus, Tycho, Archimedes, Kepler, Plato and Gassendi. The number of these spent volcanoes has been placed, on the lowest estimate, at 200,000, though the more sanguine of the observers put it not less than 1,000,000.

Fig. 44.—A Typical Lunar Crater.

Mountain-chains. There are a few mountain-chains, of which the most prominent, the Apennines, is about 450 miles long. The heights of these mountains can be determined by measuring their shadows.

Plains. The plains are represented by the darker portions of the moon's surface. They were formerly supposed to be actual seas, since water would reflect less of sun-light than land, but now they are regarded merely as old sea-bottoms, though their names "Mare Tranquillitates," "Mare Crisium," etc., have still been retained. There are 12 large plains on our side of the moon. They look darker, because perhaps the rocks of which they are composed are such that they reflect the sun-light less than the other regions.

Rills, Clefts and Rays. The other interesting features of the moon's surface are rills, clefts and rays. The *rills* are narrow, deep and crooked valleys or furrows. They may have been once the beds of dried-up streams. (Fig. 45.) *Clefts* are narrow cracks, about half a mile wide, running hundreds of miles over mountain and valley.

Rays are streaks which *radiate* from some craters like the spokes of a wheel, and pass across mountain and valley, and sometimes through craters. No satisfactory explanation of them has yet been given. The best time to see them is at full moon. (Fig. 43.)

All these surface features of the moon suggest a former period in its history, when there was probably great volcanic activity on it.

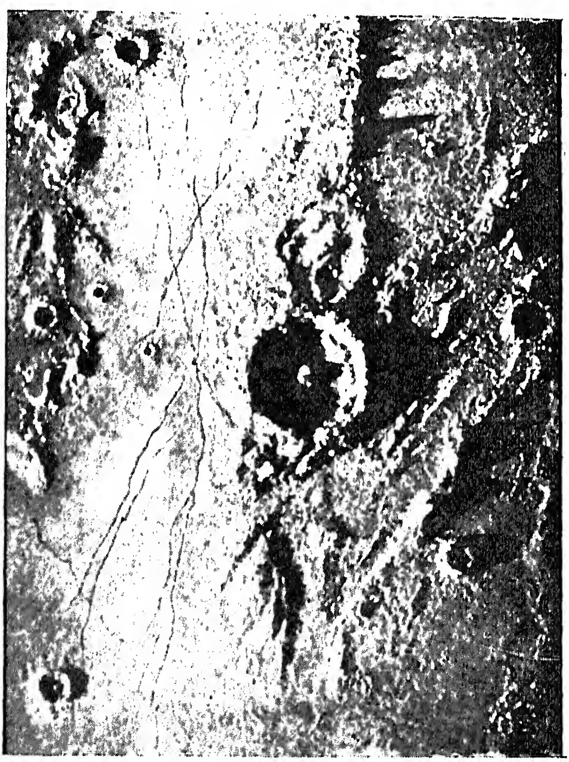


Fig 45.—The Lunar Crater Triesnecker and Lunar Rills.

50. Water on the moon. There seems to be no water whatever on the moon, and consequently no clouds, no oceans, no rivers, no lakes. If water be present there, it may

be in the solid form as ice or snow. Whenever we look at the moon, its features always stand out clear, without there being any haze or distortion at its edge, as would be if it were covered by clouds. The absence of clouds and other atmospheric phenomena proves the absence of water on the moon. The water, originally present on the moon's surface, might have united with the rocks in the process of crystallization, and have thus disappeared.

51. Atmosphere on the moon. The moon has also no appreciable atmosphere. (1) When the moon occults (Lat. *occulo*, I hide) a star, the star does not suffer change of brightness and colour gradually, as it would do if the moon had an atmosphere. Its light is extinguished *instantaneously*. This shows that star-light has not to pass through a veil of lunar atmosphere. Further, if there were an atmosphere on the moon, the star-light would be refracted by it, and one should see the star for a short time *after* it had passed behind the moon, as well as *before* it came out of it. (2) The shadows cast by lunar mountains are always seen to be black and sharply defined, and the moon's features are clearly visible without the least blurring. This would not be the case, if the moon had any atmosphere: they would look dim and hazy. The atmosphere originally present on the moon may have been absorbed by the rocks in cooling slowly.

52. Life on the moon. All the above facts about the moon's physical condition show that life (both animal and vegetable), as we see on the earth, is impossible on the moon. The surface must be all dry and barren. "It is a land of death." There are no sounds whatever to break the eternal silence, no changes, no storms, no verdure, and no wintry snow. "The moon is now a dead mass of rock, an airless, waterless and lifeless globe."

Professor W. H. Pickering is, however, of opinion that slow changes *are* going on in some of the details of the surface of the moon. He has detected evidences of activity in some reputedly dead craters, of the existence of ice and hoar-frost, and, most remarkable of all, evidences of *vegetation*.

CHAPTER VIII.

ECLIPSES.

53. Shadows. "When light falls on an opaque body, it cannot penetrate into the space behind it ; this space is called the *shadow*." Considered geometrically, it is a *solid*, not a surface.

If the source of light is a *point*, the shadow cast is called the *Geometrical Shadow*. It is always sharply defined, having no outer shadow. But the shadow cast, when the luminous body has *some magnitude*, consists of two parts, one a central dark one, called the *umbra* (Lat. *umbra*, shade), surrounded by another faintly dark, called the *penumbra* (*pene*, almost). Under ordinary conditions luminous bodies have a certain magnitude, so their shadows are always surrounded by a penumbra.

If the source of light is smaller than the shadow-casting object, the umbra will be larger than the penumbra. But if the source of light is larger than the object, the penumbra will be more extensive than the umbra.

54. An eclipse. A luminous heavenly body is said to be *eclipsed* (Gr. *ekleipo*, I fail) when (1) it is obscured by a shadow falling upon it, or (2) when it is shut out from our view by the coming of an opaque body between us and it.

55. Lunar and solar eclipses. Eclipses of the sun and the moon are caused by the revolution of the moon round the earth. The moon and the earth, being spherical opaque bodies, cast conical shadows in directions opposite to the sun, taking of course their shadows with them as they revolve. A lunar eclipse is caused by the moon passing into the earth's shadow ; a solar eclipse by the moon coming between the sun and the observer on the earth. In both cases, there are two kinds of shadows, an umbra and a penumbra, as the source of light (the sun) is larger than the earth and the moon.

56. Eclipses of the moon. When the moon, in moving along its orbit round the earth, comes in opposition, it sometimes passes into the earth's shadow. Then it is said to be *eclipsed.* As the moon revolves round the earth from west to east, in a lunar eclipse the *eastern* limb of the moon is first obscured. Lunar eclipses can take place only (1) when the centre of the moon is in or near the line joining the sun and the earth, *i.e.*, when the moon is at or near one of the nodes, and (2) when it is full.* (Fig. 46.) They may be total or partial.

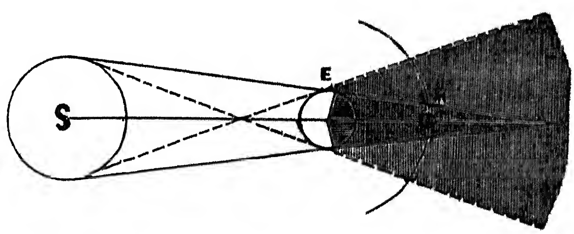


Fig. 46.—Eclipse of the Moon.

Total and partial lunar eclipses. During a *total lunar eclipse*, the *whole* disc of the moon is covered up by the shadow for some time; but, during a *partial eclipse*, the whole disc will not be obscured at any time. The northern or southern edge of the moon will escape the eclipse. (Fig. 17.) A total lunar eclipse, when central, may last for four hours. During half this time the whole of the moon's disc will be in eclipse. A lunar eclipse, total or partial, is visible at all places where the moon is above the horizon, but it will be either total *or* partial *at all* these places.

A *total eclipse* of the moon takes place when the moon passes completely into the umbral cone of the earth's shadow.

* The first condition is not satisfied at every opposition of the moon, for reasons given in Art. 63.

This is so when it is *exactly at* one of its nodes. A *partial eclipse* of the moon occurs when a part of the moon passes in the umbral cone and a part in the penumbral cone. This occurs when it is *near* one of the nodes.

Phenomena of a total lunar eclipse. "When the moon is in the penumbra of the earth's shadow, enough sun-light still strikes it to make it shine brightly ; no one could surmise that it was about to suffer eclipse. But as soon as it reaches the umbra, the (eastern) portion of its limb in the dark shadow disappears from view. (This is called the '*First Contact.*') The dark notch grows until the entire moon is immersed in the umbra." As the shadow advances, the edge of the moon that was first obscured begins to be seen, and then gradually the whole disc becomes visible. When the moon has completely emerged from the umbra, it is called '*Last Contact.*'

Though the moon is completely obscured during a total lunar eclipse, strange to say, it is usually seen shining with a dim copper-coloured light. This is because the sun-light, passing through the earth's atmosphere near the edge of the earth, is refracted by it into the umbral cone, and thus lights up the moon with a feeble ruddy light. If our atmosphere be laden with clouds, the sunlight will be intercepted by them, so the moon will be quite invisible; but this happens rarely.

If the moon falls wholly within the penumbra, without any part of it being in the umbra, there is no true eclipse, but only an imperceptible diminution of the moon's brightness. This is sometimes called a "*penumbral eclipse.*"

The circular outline of the earth's shadow falling on the moon observed at a lunar eclipse is taken as a proof of the rotundity of the earth. (*Cf.* Art. 11.)

Solar Eclipses.

57. Solar eclipses are of three kinds—total, partial, and annular.

Total solar eclipses. When the moon comes *directly* between the earth and the sun, and its shadow quite

reaches the earth, a total eclipse of the sun takes place. This occurs only when (1) the moon is at one of the nodes, (2) when it is new and (3) when it is in perigee, *i.e.*, at its *least* distance from the earth, so that the moon's angular diameter is greater than that of the sun. The moon, being smaller than the earth, the lunar shadow-cone can obscure only a small part of the earth ; it marks out a narrow track on the earth's surface, within which alone the solar eclipse is visible. (Fig. 47.) At

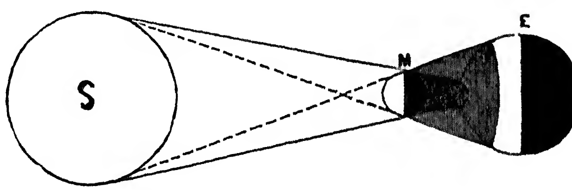


Fig. 47.—Total Eclipse of the Sun.

all places on the earth on which the umbra falls, the sun is, for a few minutes during the eclipse, totally invisible, *i.e.*, the eclipse is *total.* This area is only about 167 miles in diameter. All places within the penumbra will have a *partial* eclipse, *i.e.*, a small portion of the sun (northern or southern) *can* be seen all throughout the eclipse. This region is about 200 miles in diameter. Places beyond the penumbra see *no eclipse* at all. Hence a total solar eclipse is never visible as such at all places exposed to the sun. The totality lasts generally for about 2 or 3 minutes, at most 7 minutes—sometimes merely a few seconds,—depending upon the cross section of the umbra which reaches the earth, and therefore on the moon's distance ; but the eclipse itself lasts for about 2 hours. Professor Todd says that the great total solar eclipses of 1955 (visible in India) and of 1973 (visible in Africa) will exceed 7 minutes in duration, the longest for a thousand years.

The last total solar eclipse seen in India occurred on January 22, 1898. Its time of totality was 2 minutes. Total eclipses of the sun are very rare phenomena at a particular place. Young says that at a given station they happen only once in about 360 years.

58. Phenomena of a total solar eclipse. Howe gives the following very vivid description of these phenomena :—

"A total solar eclipse is perhaps the grandest of natural phenomena. It begins in the same way as a partial one ; just before the sun is entirely covered, the landscape assumes an unearthly hue. Awe seizes the beholder ; one sometimes sees the moon's shadow advancing through the air with terrifying swiftness as if to smite him. In a few seconds it reaches him, and the last ray of sunlight is gone ; the planets and bright stars appear. Around the black ball now hanging in the sky, the pearly corona flashes out in all its weird beauty. (*Cf.* Art. 79 and Fig. 61.) At its base glow the prominences, like rubies set in pearl. (*Cf.* Art. 79.) Men's faces grow ghastly. The silence of death is upon the beholders. Soon there is a sudden flash of sunlight at the western limb of the moon ; the corona and prominences fade apace. The gloom is overpast, and silence gives place to exclamations of wonder and delight."

Another phenomenon observed at a total solar eclipse is that certain peculiar dark quivering fringes, called "*shadow-bands*," appear upon every white surface for about a minute before and after totality.

"*The effects of a total solar eclipse on animals* are interesting. Bees return to the hive. Chickens go to roost. Caged birds put their heads under their wings. Bats and owls fly out of their accustomed retreats. Dogs are terrified, and sometimes howl dismally. Horses have been known to lie down in the public highway and refuse to advance. Some oxen were once seen to range themselves in a circle back to back, with horns outward, as if to resist an attack."

59. Importance of total solar eclipses. Total solar eclipses are considered very important by astronomers, as useful observations are made by them during totality :—

1. The surroundings of the sun, which are less luminous than the central and main body of the sun and, therefore, not

visible at ordinary times, can be observed and photographed at this time, *viz.*, the Chromosphere and the Corona. (Fig. 61.)

2. A spectroscopic examination is made of the substances present in the sun's lower atmosphere, in the prominences and the corona.

3. Astronomers can search for any small planet nearer to the sun than Mercury, which is not visible at ordinary times.

60. **Annular solar eclipse.** As the moon's orbit is elliptical, the distance between the moon and the earth is not the same at all times. When the moon comes directly between the sun and the earth, but in apogee, *i.e.*, *farthest* from the earth, the umbral cone of the moon's shadow terminates before reaching the earth, so that the moon looks smaller than the sun and, consequently, there is no *total* eclipse of the sun visible to us. (Fig. 48.) The outer rim of the sun's disc continues to be seen from that part at which the umbral cone produced meets the earth's surface,—only the central portion is eclipsed. (Fig. 49.) This phenomenon is called an *Annular Eclipse* of the sun (Lat. *annulus*, ring). In some other parts of the earth on its day-side, the same eclipse appears partial. Annular eclipses are more frequent than total ones. An annular eclipse may last for about 12 minutes.

Fig. 48.—Annular Solar Eclipse.

There can never be an annular eclipse of the moon, because, whatever the distance of the moon from the earth, the section of the umbral cone of the earth's shadow at this distance

is so extensive that it fully covers the disc of the moon, when it falls centrally on it; it never falls short of the moon.

Fig. 49.—Appearance of the Sun at an Annular Eclipse.

A solar eclipse would be, to an observer outside the earth, a partial eclipse of the earth itself, because it is obscured by the moon's shadow falling on it.

61. Partial solar eclipse. If the moon be not quite in the straight line joining the earth and the sun, the moon can be seen only partially projected on the sun's disc. In this case there will be a *purely partial eclipse of the sun* at *all* places where the sun is above the horizon. (Fig. 50.)

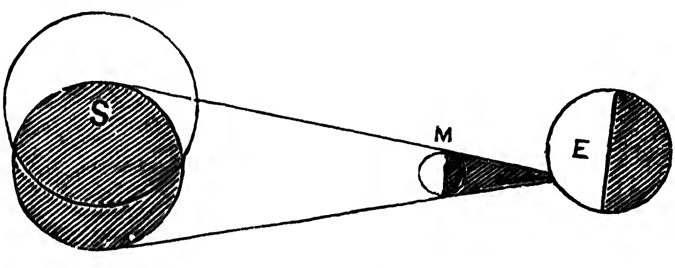


Fig. 50.—Partial Solar Eclipse.

62. Number and frequency of eclipses. The greatest number of eclipses that can occur in a year is seven, out of which 5 are solar and 2 are lunar, or 4 solar and 3 lunar. But at least two solar eclipses occur in a year. The *least* number of eclipses that can occur in a year is two, both of which must be solar. Hence there may not be a single lunar eclipse in a year.

Though, taking the whole earth into account, solar eclipses are more frequent than the lunar ones in a year (nearly in the ratio of 5 : 2), on an average *at any particular place* more lunar

eclipses are visible than solar ones. This is because solar eclipses can be seen only by those who happen to be in the narrow path of the moon's shadow on the earth's surface, and so are visible only from a limited portion of the earth; whereas lunar ones can be seen over more than half of the earth, and thus the proportion is more than reversed.

63. Why eclipses do not take place every month. If the centres of the sun, the earth and the moon were *always* in the same line, a lunar eclipse would occur every month on the full-moon day, and a solar eclipse on the new-moon day. But it is not so. The plane of the moon's orbit being inclined to the ecliptic at an angle of about 5°, half of the orbit is north, and the other half south, of the ecliptic. Hence, a lunar eclipse can take place at the time of full moon, and a solar eclipse at the time of new moon, *only when the moon is at or near one of its nodes*, because then only are the centres of the three bodies in one line. (Fig. 51.) As this coincidence happens only twice in the year, eclipses of the sun and the moon do not occur every month.*

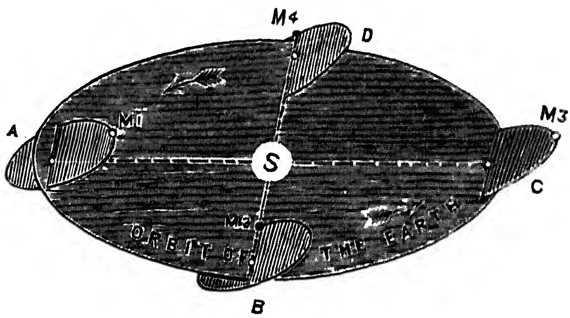


Fig. 51.—Relation between Eclipses and Lunar Nodes.

At A and C the moon is not at or near one of its nodes (being north or south of the ecliptic) at New or Full Moon; so, no eclipse can occur. But at B the moon being at the node at New Moon, a solar eclipse is possible, and at D the moon, being full and at the node, is itself eclipsed.

* The '*ecliptic*' is so called, because eclipses take place in or near its plane.

64. Lunar and solar ecliptic limits. The greatest distance of the moon from a node at which a lunar eclipse is possible is called the *lunar ecliptic limit.* It has been calculated to be about $12^\circ\ 15'$.

Similarly, the greatest distance at which the moon should be from a node for a solar eclipse to occur is called the *solar ecliptic limit.* It is about $18^\circ\ 30'$ for a partial eclipse, and $11^\circ\ 50'$ for a central one (total or annular).

65. Characteristics of lunar and solar eclipses summarised.

Lunar.	*Solar.*
1. Lunar eclipses can occur only at *Full* Moon. (Art. 56.)	1. Solar eclipses can occur at *New* Moon. (Art. 57.)
2. Lunar eclipses can be seen from the whole hemisphere of the earth where the moon is above the horizon. (Art. 56.)	2. Solar eclipses can be seen from a very limited portion of the earth. (Art. 57.)
3. Total or partial lunar eclipses will appear total or partial at *all* places on the earth where they are visible. (Art. 56.)	3. The same solar eclipse will appear total at *some* places, partial at others, and at a few places there will be no eclipse at all. (Art. 57.)
4. There can be no annular eclipse of the moon. (Art. 60.)	4. There can be annlaur eclipses of the sun. (Art. 60.)
5. During lunar eclipses the totality may last for two hours. (Art. 56.)	5. During solar eclipses the totality lasts for 3 or 4 minutes. (Art. 57.)
6. In a lunar eclipse, the *eastern* limb of the moon is first obscured, because its motion round the earth is from west to east.	6. In a solar eclipse, the *western* edge of the sun's disc is first obscured, for the same reason.

66. Recurrence of eclipses.—Before the beginning of the Christian era, a rough method of predicting eclipses was found out by Chaldean astronomers. This method is that if we start with any eclipse and reckon backwards or forwards from its date a period of 18 years and 10 or 11 days, we shall get another eclipse exactly similar to that with which we started. This period of 18 years and 11 days was called *Saros* by the ancient astronomers. As every eclipse recurs after the lapse of a saros, we can find the dates of all the eclipses of a particular year in the past or the future. For example, we can get the dates of all the eclipses of 1887 or 1923 by subtracting or adding 11 days from or to the dates of the eclipses of 1905; and it is noteworthy that each eclipse of 1887 or 1923 will be found to be quite similar in its characteristics to that of 1905, lunar, solar, total, partial, etc. The total number of eclipses in a saros is usually about 70, of which 41 are solar and 29 are lunar.

67. Consequences of the moon's revolution round the earth summarised.

1. Phases of the moon. (Art. 41.)
2. Lunar and solar eclipses. (Arts. 56,57,60,61.)
3. Moon's eastward motion among the stars. (Art. 38.)
4. Daily retardation in the time of rising of the moon. (Art. 40.)

CHAPTER IX.

THE SUN.

68. To the earth and the other planets, the sun is the most important of all the heavenly bodies. No wonder then that the ancients worshipped it as a visible emblem of divine power and purity.

69. Figure. As the sun's disc looks always circular, even though it rotates on its axis, it must be a perfect sphere.

However, recent measurements of the solar disc made by delicate instruments show that the sun's figure is variable, sometimes the polar diameter becoming longer than the equatorial diameter, and sometimes the reverse.

70. Distance. The mean distance of the sun from the earth is about 93 millions of miles. Astronomers can determine it in several ways. (*Cf.* Art. 223.) The determination of the sun's distance is regarded as one of the grandest problems of astronomy, as, by knowing it, we can know the distances of other planets and the distant stars from us. It is, therefore, called the "Measuring Rod of the Universe" or "the Astronomical Unit of Distance."

To obtain a slight conception of this enormous distance, a simple illustration or two will suffice. A train, going 1,000 miles a day, would take about 254 years to reach the sun. If an explosion took place on the sun, it would be heard by us 14 years after it occurred. Light performs this journey in 499 seconds.

71. Dimensions. The sun is 745 times larger than all the planets put together, and 1,300,000 times larger than our earth. Its diameter is 866,000 miles, or about 109½ times as great as that of the earth.

72. Diameter how determined. The sun's diameter can be determined experimentally by the following

method :—Hold a circular piece of metal or wood, about 4 inches in diameter, between your eye and the disc of the sun, at such a distance from the eye that the sun's disc is just hidden. This distance will be about 12 yards. (Fig. 52.)

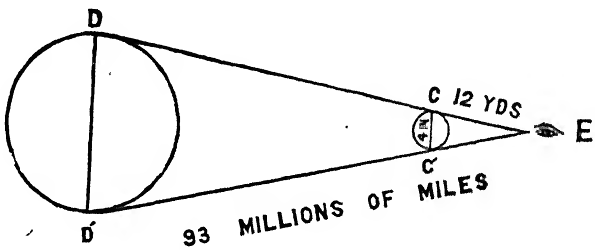


Fig. 52.—Determination of Sun's Diameter.

Let CC′=diameter of the piece.

DD′= ,, ,, ,, sun.

EC=distance between the eye and the piece.

ED= ,, ,, ,, ,, ,, sun.

equiangular

Then, in the triangles ECC′ and EDD′,

EC : CC′ : : ED : DD′ (Euclid Book VI).

But the first three terms of the proportion are known, so we can find out the fourth, DD′, which comes out to be about 866,000 miles.

73. Volume, mass, density and superficial gravity. Knowing the diameter and, consequently, the radius of the sun, we can find its *volume* by the application of the formula, $V=\frac{4}{3}\pi r^3$. This volume is 1,300,000 times that of the earth.

The *mass* of the sun is 332,000 times that of the earth.

The *density* of the sun is $=\frac{332{,}000}{1{,}300{,}000}=\frac{1}{4}$ (nearly) that of the earth. This fact shows that the materials of which the sun is composed must be comparatively lighter than those of the earth.

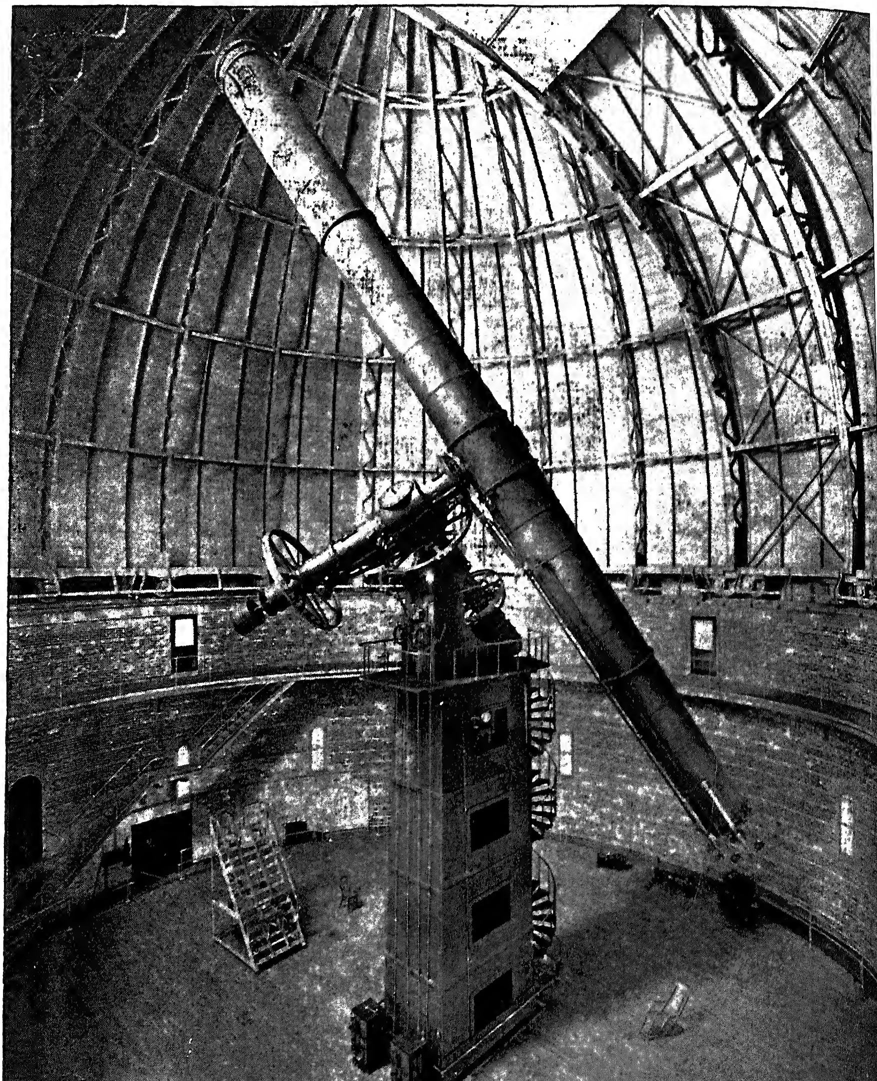


Fig. 53.—The Yerkes Telescope, Wisconsin, U. S. A.

It is the largest refracting telescope in the world. Its length is 65 ft., and the diameter of object-glass 40 inches. It was mounted in 1896-97, and cost about $ 125,000 = (Rs. 375,000.)

The superficial *gravity*, or the attraction of the sun for bodies on its surface, is about $27\frac{1}{2}$ times as great as that on the earth, *i.e.*, a body, weighing 1 lb. here, would weigh there $27\frac{1}{2}$ lbs. with a spring balance.

74. Appearance through a telescope. The sun is too dazzling an object to be seen with the naked eye. When seen through a powerful telescope, the principal features observed are the *photosphere*, the *faculæ* and the *dark spots*. (Fig. 54.)

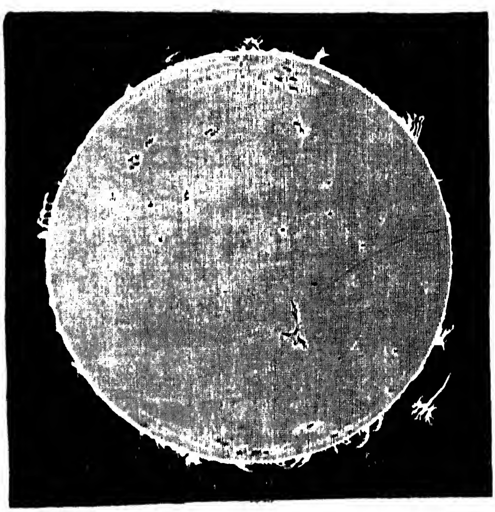


Fig. 54.—The Sun as revealed by Telescope and Spectroscope.

The Photosphere. The general bright surface of the sun is called the "*photosphere*" (Gr. *photos*, light, *sphaira*, sphere). In the telescope, it appears of a greyish colour and brighter at the centre than at the edge. Small luminous grains or nodules seem to be sprinkled about in the photosphere, and, from their appearance, are called 'rice-grains.' (Fig. 55.) The photosphere is a "cloud-like shell of intensely heated metallic gases," which ascend from the interior of the sun, and, condensing in the cold of outer space, form these luminous clouds. The

principal element found in the photosphere is carbon.

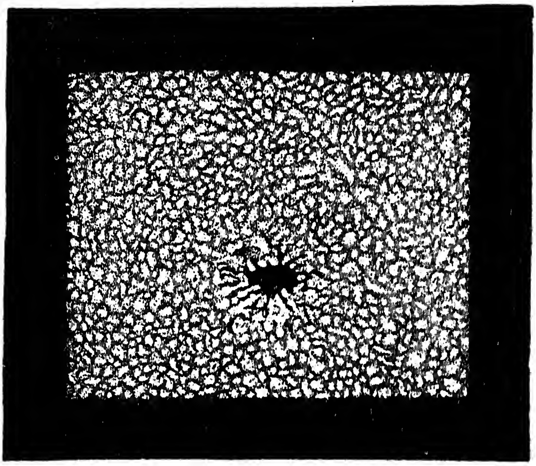


Fig. 55.—Texture of the Photosphere.

Faculæ. At some places in the photosphere, we see brighter portions than the general surface, especially in the

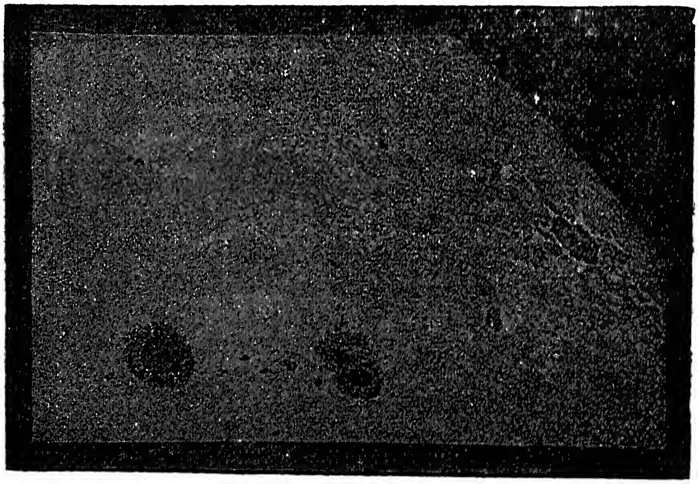
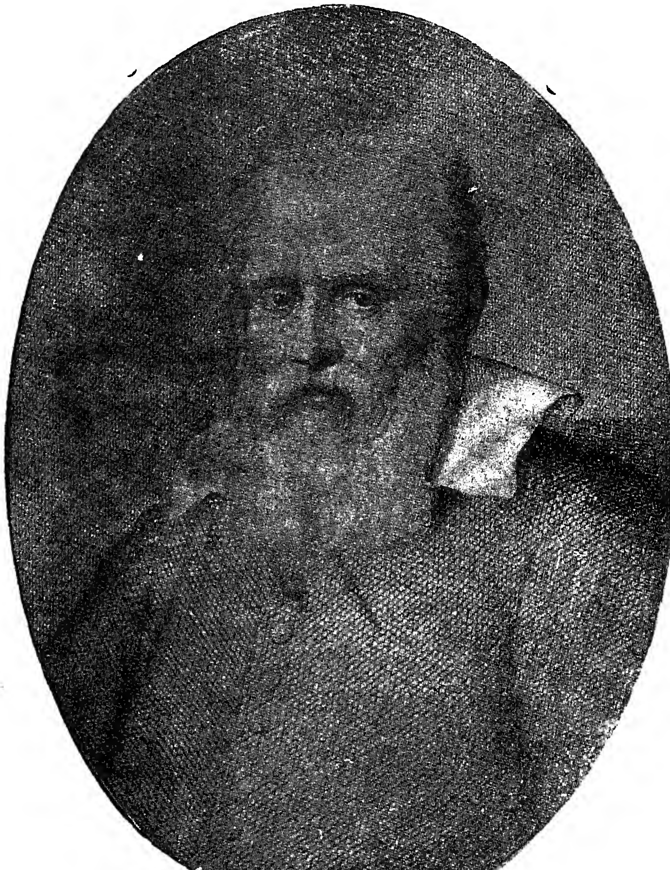


Fig. 56.—Faculæ at the Edge of the Sun.

neighbourhood of the spots, when they come to the sun's limb. These are called '*faculæ*' (Lat. *facula*, a small torch). (Fig. 56.)



GALILEO DEI GALILEI (1564-1642.)

They are supposed to be mountain-like ridges, higher than the general surface, but probably of the same material. They are sometimes 20,000 miles long and 200 miles high, so, when they pass off the edge of the sun's disc, they are seen as little projections. Sometimes, the faculæ surrounding a spot throw a luminous 'bridge' or 'tongue' right across it. (Fig. 59.)

75. Sun-spots.

Discovery. Before the invention of the telescope, the sun was regarded as an immaculate body, unlike the moon which appears all mottled even to the naked eye. In 1610, Galileo observed the sun through the telescope for the first time, and, to his surprise, discovered dark spots on its surface. They are the most interesting objects on the sun's surface. (Fig. 54.)

Professor F. R. Moulton says that the Chinese claim to have records of observations of sun-spots made centuries before their discovery by Galileo.

Forms and Dimensions. The spots have no fixed form; they continually change. However, at the middle stage of their existence they appear usually circular, and irregular at the beginning and the end. Some are observed to break up into smaller ones and vanish in a few hours.

Their dimensions are very variable. Sometimes they are of enormous size, so that they can be seen, even with the naked eye, at sunset or through a fog or coloured glass. One such was seen in 1892. It was about 150,000 miles long and 75,000 miles broad.

Appearance. They usually appear in groups, and frequently a large spot is attended by a number of smaller ones. A typical sun-spot consists of a dark central portion, surround

-ed by a lighter border. The darker portion is c
umbra ; the border is called the *penumbra*. (Fig. 57.)

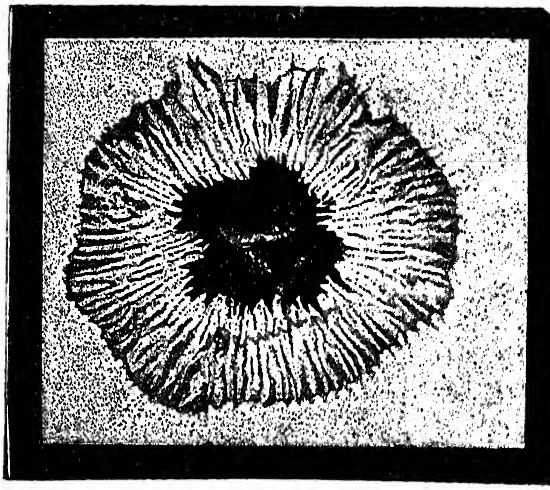


Fig. 57.—A Typical Sun-spot.

The penumbra is found to be composed of filame
"thatch straws" pointing inwards towards the umbra. (F

Fig. 58.—A Sun-spot.

Sometimes a spot may be seen which has a cyclonic motion. In such a spot the filaments are curved. (Fig. 59.)

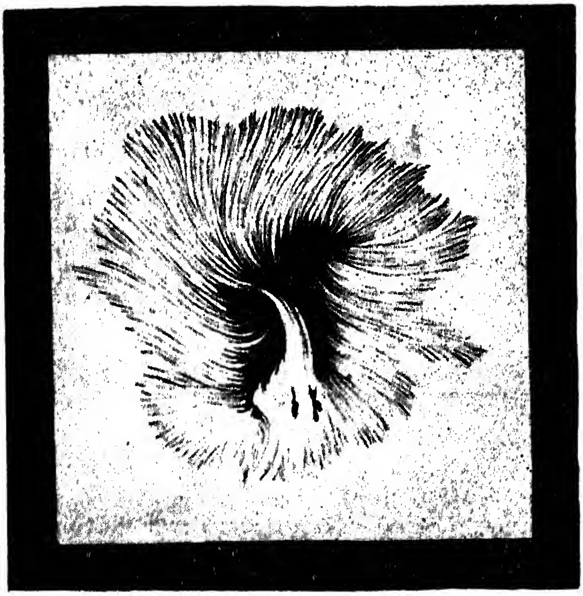


Fig. 59.—A Sun-spot with a Cyclonic Motion.

Belt

Zone of spots. The spots are not seen on all parts of the disc. They are confined to a belt or zone on either side of the sun's equator, extending from latitude 5° to 30°.

Duration. The average duration of a spot is about three or four weeks, but one is recorded to have lasted for a year and a half in 1840-41. Very often the spots last only a week, or even for a few days or hours.

Periodicity. The number of sun-spots fluctuates from year to year, but there is a recurrence of the maximum number of spots every 11·1 years. The last occurred in 1905. During a minimum period, no spots are seen for weeks together. From maximum to minimum is about 6 years, and from minimum to maximum again about 5 years.

Nature. The appearance of a spot, when on the edge of the sun, is not the same as when it is in the centre of the disc. If a spot be seen when it is at the centre, the umbra is equally surrounded on all sides by the penumbra. As it gradually advances towards the west, the part of the penumbra on the left as well as the umbra goes on diminishing in thickness, until they almost disappear at the right limb of the sun. (Fig. 60.)

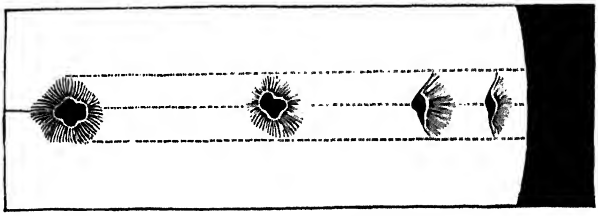


Fig. 60.—Change in the Appearance of a Sun-spot as it travels across the Disc.

The reason is that a sun-spot is, really, a shallow saucer-like hollow or depression in the photosphere, not empty, but filled with comparatively cool gases. This is proved by the fact that, when a spot comes to the limb of the sun, it sometimes appears like a 'notch' cut in its circumference. Todd, however, believes that there is good evidence that many of them are not depressions.

The umbra is really exceedingly bright, but, being less luminous than the surrounding photosphere, looks black only by contrast; in fact, it is more brilliant than a calcium light. The filaments of the penumbra are supposed to be only the prolongations of the 'rice-grains' of the photosphere.

Motions. The spots are seen always to cross the sun's disc from east to west. This is due to the rotation of the sun itself from west to east. But they have also proper motions. (*Cf.* Art. 76.)

Influence on the earth. (1) It has been noticed that the magnetic condition of our earth undergoes a violent

disturbance during the period of the maximum activity of the sun-spots. Hence these magnetic storms have also the same periodicity as the spots, *viz.*, 11·1 years.

(2) The displays of the Aurora Borealis during this period are intensely bright and most frequent.

No causes have yet been assigned to these phenomena.

76. Rotation of the sun. The spots were first observed by Galileo to travel across the disc of the sun from east to west in about $12\frac{1}{2}$ days, then to disappear behind the disc, and finally to reappear on the eastern limb in $12\frac{1}{2}$ days more. From this, he discovered that the sun rotates on its axis in about 25 days, (25·35 days). However, it has been noticed that the spots in different regions do not move with the same velocity, those near the sun's equator moving faster than those remote from it. This is because the sun's exterior being not rigid like a solid, its different parts rotate at different rates.

77. Heat and light. The sun is a tremendously hot body. Its surface temperature is about 8,000° C. Nothing exists there in the solid state—it is a globe of white-hot vapours. The heat which it sends in a second is enough to boil 600,000,000 tons of *ice-water.* The earth receives only $\frac{1}{2,200,000,000}$ of the heat.

On account of this blazing heat, the sun shines by its own light, and consequently shows no phases. The intensity of sun-light is not the same on all parts of its disc. The edges are less bright than the centre. It is calculated that 600,000 moons would be required to give us as much light as the sun gives off on a cloudless day. Two-and-a-half billions of our most powerful electric lights would match the sun in brilliancy.

78. Composition. By splitting up sunlight in a spectroscope attached to the eye-piece of a telescope, we

know that many of the elements found on the earth are also present on the sun. About 36 terrestrial elements are now known to exist in the sun, all in the vaporous state, as, hydrogen, carbon, iron, calcium, copper, manganese, sodium, nickel, etc. All these elements, with the exception of hydrogen and carbon, are *metals*. Helium, a new element which was supposed to exist only on the sun, has recently been discovered also in a terrestrial substance called cleveite. However, no trace has been found in the sun of such important elements as oxygen, chlorine, nitrogen, sulphur, phosphorus and mercury.

79. The sun's surroundings or appendages. The sun that we usually see is not the whole of it. There is an atmosphere that surrounds it, which is invisible at ordinary times, owing to the dazzling splendour of the central globe. However, at a total solar eclipse, when the whole disc of the sun is obscured by the moon, we can seé the surroundings of the sun. Hence the importance of such an eclipse.

Chromosphere. Just outside the photosphere can be seen an atmosphere, which is called the "*chromosphere*" (Gr. *chroma*, colour, and *sphaira*, sphere), because it is of a brilliant scarlet colour. It is about 5,000 miles in height. The principal elements found in it are hydrogen, helium and calcium. It is not so luminous as the photosphere.

Corona. Then we also see, during a total solar eclipse, when the last ray of sunlight vanishes, the sun surrounded by a beautiful halo of pearly light, very bright near the sun, but fading away into faint streamers or rays, which extend to thousands, and sometimes to millions, of miles. It is called the "*corona*" (Lat., *corona*, crown), because "it is a crown upon the king of day." Its shape and brightness are different at different eclipses. (Fig. 61.) It is "the most beautiful and impressive of all natural phenomena." The spectroscope has revealed iron and an unknown element in it called the

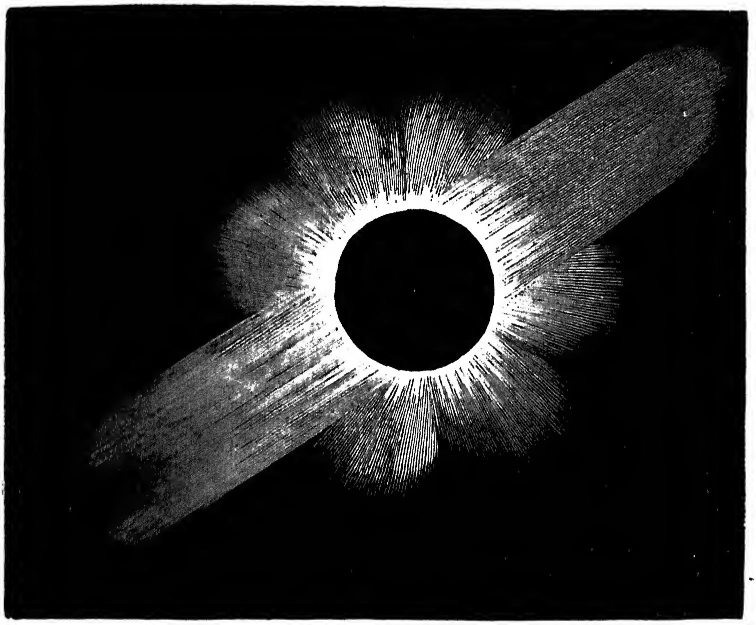


Fig. 61.—The Corona, July 29, 1878.

coronium. Its nature has not yet been satisfactorily explained. It is, however, an envelope of extremely *rare* gases, in which solid particles of dust and liquid globules are probably sprinkled about. This is shown by the fact that some comets have passed straight through it, without in any way being disturbed. All attempts to observe the corona without a total solar eclipse have failed.

Prominences. Again, at such an eclipse, large masses of lighter vapours of the chromosphere shoot up into the corona, taking fantastic shapes. These are called "*prominences*" or "*Red Flames*" from their colour which is usually scarlet. They are composed chiefly of hydrogen and helium. They can now be observed with the spectroscope or photographed, even when there is no solar eclipse. (Figs. 62, 63.)

Fig. 62.—Solar Prominences.

They are of two kinds, "*quiescent*" and "*eruptive*." The former are of enormous size, but faint, and remain unchanged for days together; the latter are more active and brilliant, changing their appearance with great rapidity, and frequently moving with a velocity of 200 miles a second. The prominences have the same periods of maximum and minimum

activity as the spots, *viz.*, 11·1 years, and are associated with magnetic storms.

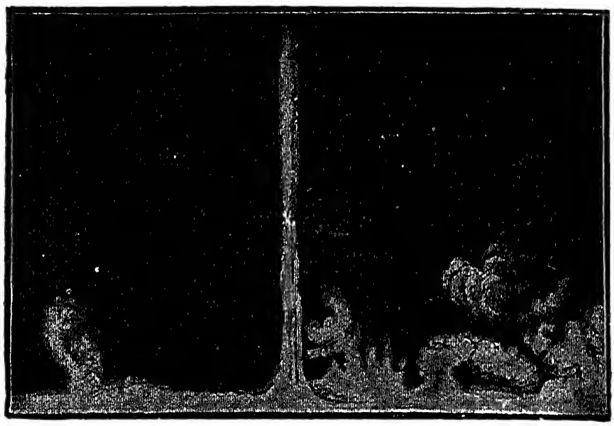


Fig. 63.—Solar Prominences.

80. Summary of the physical constitution of the sun. The central mass of the sun is probably composed of gases, but in a state quite unfamiliar to us, on account of their enormous temperature (not attainable on the earth) and great compression. This central body is surrounded by a series of layers or shells. There is first the photosphere, which is probably a shell of luminous clouds, consisting of, perhaps, solid or liquid particles floating in an atmosphere of less condensible gases. The principal element found in it is carbon. Immediately on the photosphere lies the very thin shell of the chromosphere. The chromosphere and the prominences are made up of lighter permanent gases, like hydrogen and helium, not easily condensed. Still above the chromosphere is the corona, which is, properly speaking, not an envelope, but a luminous appendage of the sun. The corona is, probably, composed of gases of extreme rarity, in which finely-divided particles of dust and liquid globules are scattered about.

81. Maintenance of solar heat. A body like the sun, pouring out such a tremendous amount of heat and light, must cool down, unless they are replenished. An interesting question, therefore, arises, how is it that the sun does not become cold? Various theories are put forth to answer this question.

(1) The "*Theory of Combustion*" attempts to explain it by saying that the burning of substances present in the sun produces heat enough to supply the loss. But this theory is untenable, for the whole mass of the sun would have been consumed on this supposition in 6,000 years.

(2) "*The Meteoric Theory.*" Some try to prove that the fall of meteors into the sun generates sufficient heat by impact to maintain the supply. But only a small fraction of the heat of the sun can come from this source.

(3) The best of all theories is Helmholtz's "*Theory of Shrinkage.*" It supposes that the whole mass of the sun has been shrinking slowly but continuously, each particle falling towards the centre and thereby producing heat by compression. The amount of shrinkage is only about 10 inches a day, so, during the last 6,000 years, it could not have been noticed, even by the best modern instruments. It is, however, enough to keep up the supply of solar heat.

(4) "*Radium Theory*".—The most recent theory about the maintenance of solar heat is suggested by the discovery of radium and other radio-active elements, which are found to have the property of *emitting enormous quantities of heat* spontaneously. We know that helium, which is a decomposition-product from radio-active substances, is present in the sun in very large quantities, and it is possible that the sun contains enormous quantities of radio-active matter constantly giving off heat.

82. Future and past of the sun.

According to Newcomb, the sun cannot go on contracting for more than 5,000,000 years without *ceasing to be gaseous.* Its temperature must then fall,

so, he says, the sun will continue to give off its present heat for 10,000,000 years from the present time. It is also calculated that the sun could not have been more than 18,000,000 years old. On the theory of shrinkage, however, it must have been vastly larger in the remote past than it is now. But if we suppose that there exist in the sun large masses of radio-active substances, the duration of the sun's age may be increased to an enormous extent, and its heat may be kept up for untold millions of years.

83. The sun's motions summarised. The sun has two apparent and two real motions.

(1) The sun's apparent *daily* motion from east to west, caused by the real rotation of the earth on its axis.

(2) Its apparent *annual* motion from west to east among the stars, caused by the revolution of the earth round the sun.

(3) The sun's real motion of *rotation* on its axis in about 25 days.

(4) The sun has been found to *move in space*, along with the whole solar system, towards the star Vega in the constellation of Lyra (close to the constellation of Hercules), at the rate of 11 miles a second. (*Cf.* Art. 188.)

84. Influence of the sun.

(1) The sun lights up the earth and other planets by its beams, and warms them by its heat.

(2) The radiations from the sun enable plants to decompose the poisonous carbonic acid gas of our air into carbon and oxygen, of which the carbon serves as the food of plants, and oxygen is useful for animals. Thus the sun builds up the vegetable kingdom. But animal life is impossible without vegetable life. Therefore, without solar rays, both animals and plants would perish.

(3) All the useful work of the world, done by men or animals or by machinery, is really done by the sun. For, without food, a man or an animal cannot work, and, whether it be animal or vegetable food, it is derived ultimately from the vegetable world, which owes its existence to the sun's action.

Again, machinery is driven by steam or electricity, which are generated by burning coal. But we know that coal is the remains of ancient vegetation. Other forms of terrestrial energy* may, similarly, be shown to be due to the solar energy. Therefore, all the work of the world—heavy or light—is indirectly done by the energy supplied by the sun.

(4) The sun, by its powerful attraction, keeps the planets and other bodies of the solar system in their orbits, compelling them to revolve round it in ellipses. Without this supreme control, the system would be broken up. Hence the sun is our ruler too.

(5) Our moon shines by the borrowed light of the sun; we are, therefore, indebted to the sun also for moon-light.

(6) Physical geography teaches us that, without the sun, there could be no clouds, neither rain nor rivers, no winds, no ocean-currents, no glaciers, nor some other physical phenomena.

* '*Energy*' means the power of doing work.

CHAPTER X.

THE SOLAR SYSTEM.

85. The *Solar System* is the name given to a group of heavenly bodies which consists of (1) the sun in the centre, and the following bodies which revolve round it :—

(2) (*a*) Eight large bodies (of which our earth is one) called the *planets*. They are Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus and Neptune. Most of them are attended by *satellites* (moons) revolving round them ; the earth has 1, Mars 2, Jupiter 7, Saturn 10, Uranus 4, and Neptune 1. (*b*) More than 600 small planets, called the *asteroids*, revolving between the orbits of Mars and Jupiter. They are also called "*Minor Planets*."

(3) *Meteoric bodies* moving in swarms.

(4) *Comets*.

(5) *Zodiacal Light*.

The system is so called from Latin *sol*, the sun, because it is the central body, round which all the others revolve. The system is also called the "*Planetary System*." (*Frontispiece.*)

Planets—A General Description.

86. Classification. The planets are divided, according to the position of their orbits, into two classes :—

(1) *Interior* or *Inferior Planets* are those whose orbits lie within the orbit of the earth. Mercury and Venus are interior planets.

(2) *Exterior* or *Superior Planets* are those whose orbits lie without the orbit of the earth. Mars, Jupiter, Saturn, Uranus and Neptune are exterior planets.

87. How interior planets can be distinguished from exterior planets.

(1) The interior planets go through all the phases like

the moon ; while exterior planets only show a gibbous or full phase. (Fig. 67.)

(2) The interior planets are never seen at midnight, because, being very near the sun, they can be seen always in close neighbourhood of it, and at midnight we are on the side of the earth opposite to the sun. They can be seen only in the evening after sunset, or in the morning before sunrise, and never on the side opposite to the sun. The exterior planets are visible at any time, even at midnight. Fig. 66 will make this clear.

(3) An interior planet can come directly between the sun and the earth. When it does so, it is seen like a dark spot on the surface of the sun. This is called a *transit* of the planet. (Fig. 68.) An exterior planet can never come between the earth and the sun, and so cannot cause transits.

(4) The distance of an interior planet from us varies at different times; therefore, its *apparent size* will also vary. (Fig. 69.) An exterior planet also varies in size, but not to so great an extent as an interior one. (Mars is, however, an exception.)

88. Minor or Terrestrial and Major Planets.

Again, the planets have been divided by Humboldt, according to their size, into *minor* or *terrestrial* and *major* planets. Mercury, Venus, Earth and Mars are *minor* planets; Jupiter, Saturn, Uranus and Neptune are *major* planets. The chief points of distinction between them are :—

1. The minor planets are comparatively small bodies ; while the major ones are "giants in size." (Fig. 64.)

2. The minor planets are solid and very dense ; the major ones are less dense, being composed mostly of gases.

3. The minor planets have each an atmosphere of *small* mass compared with their own mass ; while the atmospheres of the major planets are very *extensive* and dense.

4. The minor planets have very few moons ; the major ones, except Neptune, are liberally supplied with satellites.

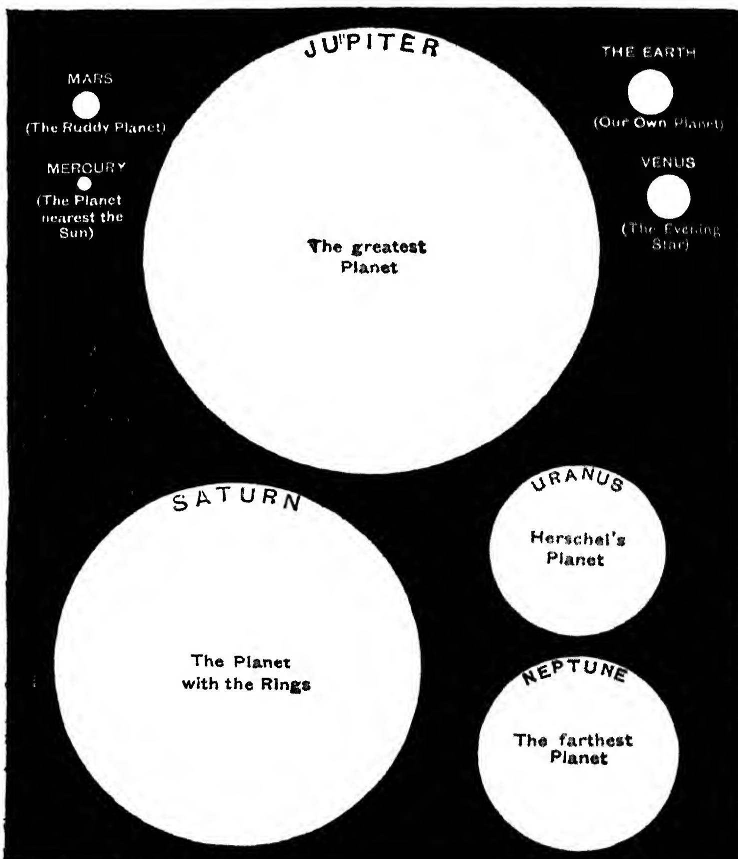


Fig. 64 —Relative Dimensions of Planets.

89. Herschel's illustration of the dimensions and distances of the sun and the planets.

Sir John Herschel in his "*Outlines of Astronomy*" gives the following beautiful illustration of the relative dimensions and distances of the planets:—"Choose any well-levelled field. On it place a globe two feet in diameter. This will represent the sun. *Mercury* will be represented by a grain of mustard-seed on the circumference of a circle 164 feet in diameter for its orbit; *Venus*, a pea, on a circle of 284 feet in diameter; the Earth, also a pea, on a circle of 430 feet; *Mars*, a rather large pin's head, on a circle of 654 feet; the *asteroids*, grains of sand, on orbits having diameters of 1000 to 1200 feet; *Jupiter*, a moderate-sized orange, on a circle nearly half a mile across; *Saturn*, a small orange on a circle of four-fifths of a mile; *Uranus*, a full-sized cherry or small plum, upon a circumference of a circle more than a mile in diameter; and, finally, *Neptune*, a good-sized plum, on a circle about $2\frac{1}{2}$ miles in diameter."

90. Apparent and real motions of planets.

Apparent motions. The planets do not appear to move uniformly in one direction. For some time they are observed to move among the stars from west to east. Then they appear to be stationary for a time. After this they apparently go retrograde, *i.e.*, shift slightly towards the west, then become stationary again, and resume their eastward journey once more. But it is found that their motion towards the east is always in excess of their westward motion. Thus all planets complete their circuits in the heavens from west to east in certain periods, though these paths will be found to consist of a number of loops, on account of their direct, stationary and retrograde motions.

The motion of a heavenly body among the stars from *west to east* is called "*Direct Motion*," and its motion from *east to west* is said to be "*Retrograde Motion*."

The *Ptolemaic Theory* attempted to explain these irregular motions by regarding the earth as the fixed centre, round which the sun and the planets revolved. After holding sway for 14 centuries, it gave place in 1543 to the *Copernican Hypothesis*, which considers the sun as the centre of the system, round which all the planets, including the earth, revolve in

different periods according to their distances from it. This heliocentric view satisfactorily accounts for the capricious movements of the planets by regarding the earth as a *moving observatory*, whose own motion makes theirs look so complicated.

Real motions. All the planets go round the sun from *west to east*, and are observed through the telescope to rotate on their axes in the same direction. Their satellites also revolve round them from west to east, except those of Uranus and Neptune and a few of Jupiter and Saturn, which are found to have a retrograde motion.

The telescope reveals all the planets to be *spheroidal.*

91. Shapes and inclinations of the orbits of planets. The orbits of all the planets are ellipses, and the sun is in one of the foci, though the ellipses differ very little from circles.

The planes of their orbits are slightly inclined to the ecliptic, so that they confine their wanderings to a region in the heavens about 8° on either side of the ecliptic. This region is called the *Zodiac.*

The two points where the orbit of a planet intersects the ecliptic are called "*nodes.*"

92. Kepler's Laws. Before the time of Kepler (1571—1630), the orbits of planets were supposed to be *circular.* By his laborious observation of Mars extending for 17 years, he discovered three famous laws, which govern the motions of planets. These are known as *Kepler's Laws.* They are :—

1. *Each planet revolves round the sun in an elliptical orbit, having the sun in one of the foci.*

2. *The radius vector of a planet describes equal areas in equal times.*

3. *The squares of the periodic times of the planets are proportional to the cubes of their mean distances from the sun.** This is known as the "*Harmonic Law.*"

* The *mean distance* of a planet is half the sum of its greatest and least distances from the sun.

JOHANNES KEPLER (1571-1630.)

The discovery of this law made him so enthusiastic that he wrote:—"The die is cast; the book is written to be read either now or by posterity, I care not which. It may well wait a century for a reader, as God has waited 6,000 years for an observer."

The first law shows the *form* of a planet's orbit. (For the properties of the Ellipse, the student is referred to Art. 25.)

The second law shows with what *velocity* a planet moves in the different parts of its orbit. In Fig. 65, the shaded areas described in equal times are all equal; but as the arcs AA_1, A_2A_3, A_4A_5, are unequal, the velocities in these parts must be different. Also, as the arc AA_1 is greater than the arc A_2A_3 or A_4A_5, it follows that, the nearer a planet is to the sun, the greater is its velocity. (The *Radius Vector* of a planet is the line joining the planet and the sun at any point in its orbit.)

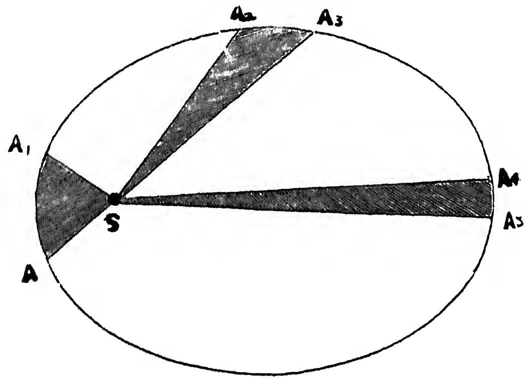


Fig. 65.—Illustrating Kepler's Second Law.

The third law shows the relation between the periodic times of two planets and their distances from the sun. If P_1, P_2 be the respective periodic times of two planets and D_1, D_2 be their distances from the sun, then the third law says,

$$\frac{P_1^{\,2}}{P_2^{\,2}} = \frac{D_1^{\,3}}{D_2}$$

The third law has been found true also in the case of the earth. This is strong evidence that the earth is a planet.

93. Elongation, Conjunction, and Opposition of planets. The *Elongation* of a planet is the angle formed at the earth by two lines drawn from it to the planet and the sun respectively.

When a planet comes between the earth and the sun, it is said to be in "*Inferior Conjunction.*" (Fig. 66.) Only interior planets can be in inferior conjunction. When the sun is between the earth and an interior planet, the planet is said to be in "*Superior Conjunction.*"* When a planet is in inferior or superior conjunction, its elongation is 0°, and it rises and sets with the sun. (Fig. 66.)

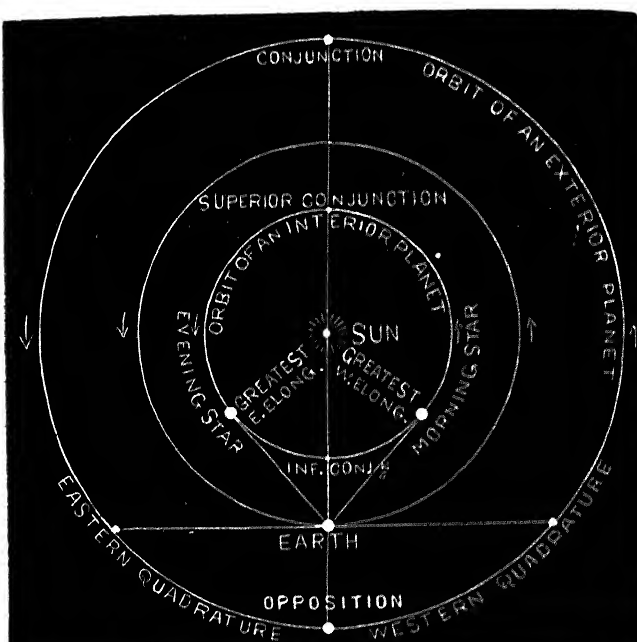


Fig. 66.—Conjunction, Opposition, Quadrature, etc., of Planets.

When the earth is between a planet and the sun, it is said to be in *Opposition.*" Only exterior planets can come in

* We call the corresponding position of an *exterior* planet simply "*Conjunction.*"

opposition. For this reason an interior planet cannot be seen at midnight. When a planet is in opposition, its elongation is 180°, and it rises at sunset. (Fig. 66.)

When the elongation of a planet is 90°, the planet is said to be in "*Quadrature.*" (Fig. 66.)

94. Morning and Evening Stars. An interior planet is said to be a "*Morning Star,*" when it rises between midnight and the following sunrise. It is a morning star from inferior to superior conjunction. When an interior planet is seen after sunset above the western horizon and sets before midnight, it is called an "*Evening Star.*" It is an evening star from superior to inferior conjunction. (Fig. 66.)

95. How planets can be distinguished from stars.

(1.) Planets are wandering bodies, *i.e.*, they move among the stars, completing their circuits in the sky in fixed periods; while the stars are fixed, *i.e.*, their relative distances from one another do not change. (This is, however, not strictly true, as we shall see in Art. 189.)

(2.) Planets shine with a steady light; stars with a twinkling light. (But the condition of the atmosphere and also the position of the body in the sky have much to do with the character of light.)

(3.) Planets, when seen through a telescope, present distinct spheroidal discs; whereas, the stars, when viewed even through the best instruments, appear as mere points of light.

(4.) Planets are, comparatively, cold bodies, shining by the light of the sun; the stars, like the sun, are hot self-luminous bodies.

96. How the length of the day of a planet is determined. We notice, through the telescope, a spot or any permanent dark marking near the equator

of a planet, and watch how long it takes to pass from one side of the disc to the other, disappear, and come back to the same position. This time is the time of rotation, or the length of the day, of the planet.

97. Determining the seasons on a planet. We observe a particular spot on a planet, and notice the direction in which it moves across the disc. This will show us the plane of rotation of the planet. Its plane of revolution can be known by watching its movement among the stars. Knowing the inclination between these two planes, we can say how the seasons change on the planet.

98. How to determine the distance of a planet. If we watch the motion of the planets among the stars, and thus determine their periods of revolution, their relative distances from the sun can be found out by applying Kepler's Third Law. Now, if we also ascertain the distance of any *one* planet from the sun *in miles*, we can determine the distances of the other planets also in miles.

99. How the size of a planet is found. Knowing the distance of a planet in miles and its angular diameter, we can find by trigonometry its diameter in miles. Hence we can find the area of its surface and its volume. (Area $=4\,\pi r^2$, and volume $=\frac{4}{3}\pi r^3$, where $r=$ radius of the planet.)

100. The mass and density of a planet how determined. The mass of a planet can be determined by ascertaining the amount of attraction exerted by it upon other bodies. Such bodies may be (1) its own satellites, (2) comets rushing past it, or (3) other planets.

Dividing the mass by the volume, we get the density of the planet.

101. How to detect the presence of an atmosphere on a planet. (1) If the shadows of

high objects on the planet do not appear intensely black and sharply defined, and if the objects themselves look dim, we can suspect the presence of an atmosphere.

(2) If, when the planet occults a star, the light of the star is *not suddenly* quenched, but fades away *gradually*, we may attribute it to the presence of an atmosphere on the planet.

(3) In the case of an interior planet, if, when it enters upon a transit across the sun's disc, a faint ring of light is observed surrounding the planet, it is an evidence of the existence of an atmosphere on the planet.

102. **How the physical features of a planet are known.** These can be studied with the telescope, and careful drawings can be made of the appearances and markings at different times. Photography has also begun to be used for this purpose with some success.

CHAPTER XI.

PLANETS—DETAILED DESCRIPTION.

MERCURY.

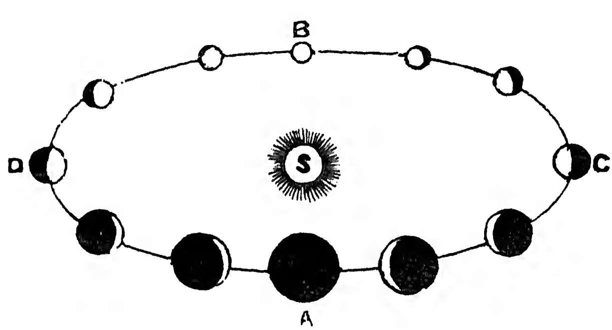
103. **Distance, diameter, orbit.** Mercury is about 36 millions of miles from the sun. Its diameter is about 2,800 miles. The orbit of Mercury is the most eccentric of any of the orbits of the eight planets.

104. **Revolution and rotation.** It revolves round the sun in 88 days. Its time of rotation, formerly estimated at 24 hours, was discovered by Schiaparelli in 1889 to be also 88 days. This discovery was confirmed in 1896 by Mr. Lowell. Hence, Mercury turns the same side to the sun, which must be "always exposed to a sevenfold African blaze of sunbeams," while the other half must be always sunless and intensely cold.

105. **Appearance to the naked eye.** Mercury is so very near to the sun, that it cannot easily be seen with the naked eye. It is, however, visible at certain times near the western horizon just after sunset, or at the eastern horizon before sunrise. The best time for seeing it in the evening is in March or April, when the planet is at its eastern elongation. When it is a Morning Star, it is best seen in September or October. The greatest altitude which it can attain in either case is about 29°, so that it is never visible on the meridian.

106. Telescopic appearance and phases. When seen through a telescope, Mercury is found to show the same phases as our moon does. When Mercury or Venus is in inferior conjunction, it rises and sets with the sun, and its dark side is turned towards us, so we cannot see it. (Fig. 67, A.) At superior conjunction, as the whole of its lit-up side is turned towards us, we should see it full; but, as it here also rises and sets with the sun, it is lost in its rays. (Fig. 67, B.)

Superior Conjunction.



Inferior Conjunction.

Fig. 67.—Phases of Mercury or Venus.

At C and D it appears half. Between A and C or A and D it is of a crescent shape, and between B and C or B and D it is gibbous. These phases prove the revolution of Mercury and Venus around the sun.

Faint dark markings are observed on its surface, but we cannot say anything about their nature.

107. Transits. When Mercury is at inferior conjunction and near one of its nodes, it is seen by us like a round dark spot crossing the disc of the sun,—too small,

however, to be seen without a telescope. (Fig. 68, M.) This passing is called a "*transit*." Such transits can occur only on about May 7th and November 9th. They are, however, of little scientific interest.

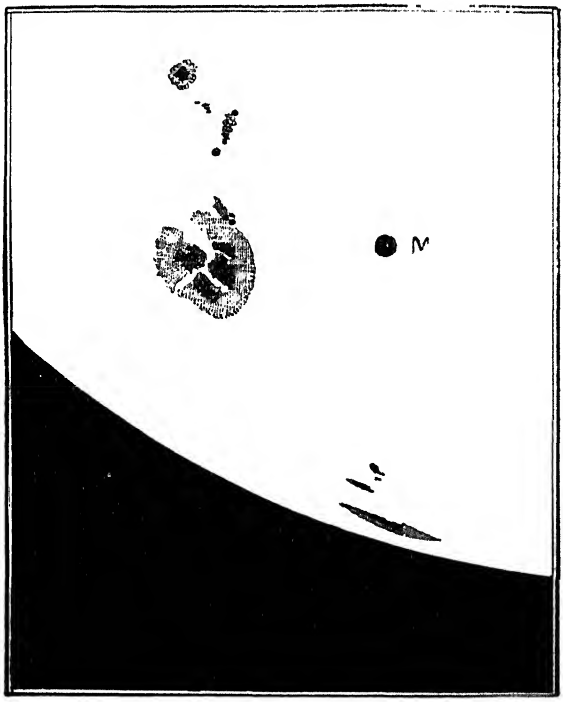


Fig. 68.—Mercury in Transit across the Sun.

108. Physical condition. As the markings on the surface of Mercury are not well defined, we do not get sufficient information about its physical condition. However, the spectroscope has shown the presence of water-vapour. From this, we should conclude that it has also air and water. But the atmosphere must be very rare.

Young says "Mercury is exceptional in the solar system in various ways. It is the *nearest* planet to the sun, receives *the most light and heat*, is the *swiftest* in its movement, and *has*

the most eccentric orbit, with the *greatest inclination to the ecliptic*. It is also the *smallest* in diameter, has the *least mass*, and the *greatest density* of all the planets."

VENUS.

109. Distance, diameter, orbit, revolution and rotation. The mean distance of Venus from the sun is about 67 millions of miles. Its diameter is about 7,800 miles. Its orbit approaches nearest to a circle. When it is at inferior conjunction, it is nearer to us than any other heavenly body, except the moon and the recently discovered asteroid "*Eros*."

Its period of revolution round the sun is 225 days. Its rotation-period was once taken to be about 23¼ hours, but Schiaparelli showed that it is the same as its revolution-period, *viz.*, 225 days. This is confirmed by Perrotin, Lowell and other observers. The axis of Venus is inclined 80° to the ecliptic, consequently the seasonal changes there are more extensive than on the earth.

110. Brilliancy. It is the brightest and the most conspicuous of all the planets. "All the heavenly host—even Sirius and even Jupiter—must pale before the splendid lustre of Venus, the unrivalled queen of the firmament." Indeed, it is so brilliant that sometimes on a very clear sky, when it is in the crescent phase, it is visible even during the day with the naked eye for about 10 weeks, and casts distinct shadows of objects at night.

111. Appearance. Venus can generally be seen either just after sunset near the western horizon, or before sunrise at the eastern horizon.

112. Evening and Morning Star. When it is visible after sunset in the west, it is called the *Evening Star;* when before sunrise in the east, it is called the *Morning Star*. In both cases, its height above the horizon is at first very small, but gradually increases, until it reaches its maximum, which

is 47°, after which it gradually retreats to the horizon. From A to B in Fig. 66, *i.e.*, from inferior to superior conjunction, Venus is a morning star, and from B to A it is an evening star. The ancients, believing that two different bodies were observed, called the Morning Star *Lucifer* or *Phosphorus*, and the Evening Star *Vesper or Hesperus*.

113. Phases. As explained in Art. 106, Venus goes through the same phases as Mercury or our moon. They were discovered by Galileo in 1610. (Fig. 69.)

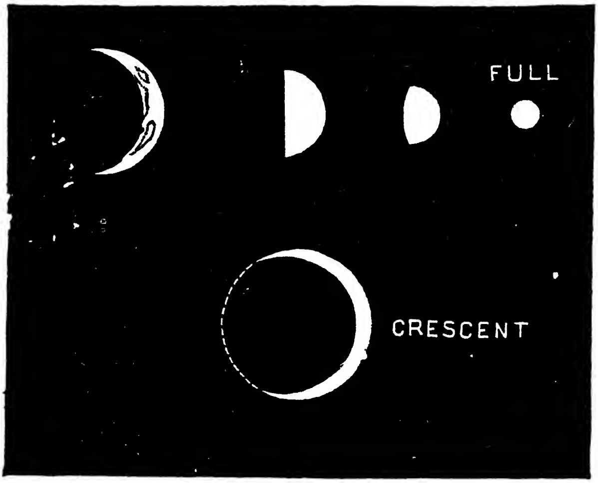


Fig. 69.—Apparent Size of Venus at Different Phases.

Venus is brightest, not when full, but during the crescent phase,° because the crescent forms part of a circle six times larger than when it is full. When Venus is nearly between us and the sun, it is a fine crescent, and it is about 26 millions of miles from us (93—67). But when it is on the opposite side, it is full; then its distance from us is 160 millions of miles (93+67). The two *distances* being as 26 : 160, the *size* of Venus in the two positions will be as 160 : 26, *i.e.*, nearly 6 : 1. (Fig. 69.)

passes across the sun's disc as a round dark spot from east to west—easily seen with the naked eye through a shade-glass. Transits of Venus are very rare phenomena, but they are very important, as they enable astronomers to determine (1) the sun's distance from the earth, and (2) whether Venus has an atmosphere. The next transit will occur on June 8th, 2004; the last took place on December 6th, 1882.

115. Physical condition. Very little is known of the surface of Venus. Rarely, spots of a leaden hue are seen. Its density being almost equal to that of the earth, it is probably a solid body.

It owes its brilliancy to the fact that it is surrounded by a dense atmosphere thickly laden with clouds at all times, and clouds reflect light more powerfully than land. Water must, therefore, be abundant on the planet. According to Howe, "There may not be a square foot of dry land to vary the monotony of a universal ocean." The spectroscope also shows the presence of water-vapour on Venus.

The presence of atmosphere is proved by the fact that, when Venus enters upon a transit, a faint delicate ring of light is observed surrounding the portion of the disc of the planet outside the sun. This is the light of the sun refracted and reflected by the atmosphere of Venus.

MARS.

116. Distance, diameter, orbit. The mean distance of Mars from the sun is 141 millions of miles. Its orbit is, however, so eccentric that, when nearest to the sun, (as at M in Fig. 70) it is only 128 millions of miles, and, when farthest (as at M″), it is 154 millions of miles from the sun. Its diameter is 4,300 miles, *i.e.*, about half that of the earth.

117. Revolution and rotation. It takes 687 days to revolve round the sun. It rotates on its axis in about

$24\frac{1}{2}$ hours. The axis of rotation being inclined about 65° to the plane of its orbit, Martian seasons resemble our own, but they are about twice as long.

118. Appearance. Mars can best be seen with the naked eye when it is in opposition, because it is then full and very near the earth, and rises at sunset. The oppositions take place every 780 days, but, owing to the eccentricity of the orbit, some oppositions are extremely favourable. (Fig. 70, M.) These occur about every 15 years. The last was in August 1907. At such times, Mars being only 35 millions of miles from

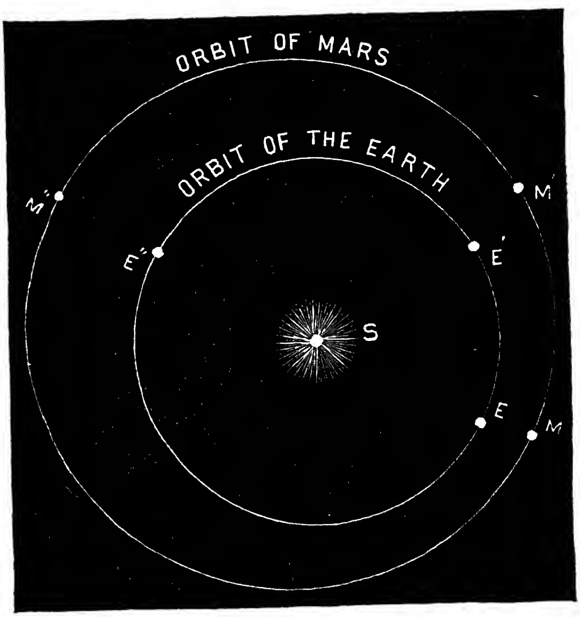


Fig. 70.—Favourable and Unfavourable Oppositions of Mars.

M, a very favourable opposition.
M′′, „ „ unfavourable „

the earth, its apparent diameter is very large, and it shines with a fiery red light, rivalling Jupiter in brilliancy. No other

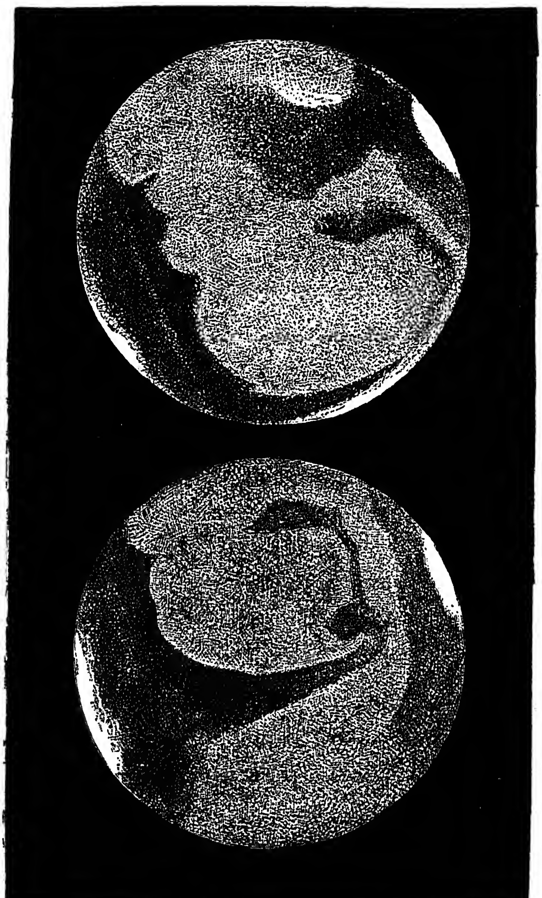


Fig. 71.—Telescopic Views of Mars, showing the lands, seas and the ice-caps at the poles.

planet shines with a ruddy light, hence the name "*Ruddy Planet.*"

119. Physical features.

Continents and seas. When seen through a telescope, the planet does not appear all red, but markings of a dark olive-green hue are seen on a bright orange-coloured surface. The bright portions are supposed to be continents and the darker portions seas. But it is doubtful whether they are actual seas or old sea-bottoms, as sometimes "canals" have been seen in these "seas," and besides, these dusky areas assume different shades of colour at different Martian seasons. According to Mr. Lowell, the dark areas are covered with some sort of vegetation, while the orange-coloured regions are barren deserts, irrigated by the "canals." On Mars the proportion of "land" to "water" is 5 : 3, hence "clouds are rarities there." The boundaries of the "continents" and the "seas" are *not fixed* as on the earth. (Fig. 71.)

Polar caps. Around the poles of Mars, dazzling white patches are observed, which are supposed to be "snow or ice-caps," because when it is summer in the Martian northern hemisphere, the north polar cap diminishes in size, while the southern one becomes larger and larger; and *vice versa* during the winter. (Fig. 71.)

Canals. In addition to these three classes of permanent markings, in 1877 Schiaparelli discovered some of the markings which are called "canals." They appear as fine, straight lines, forming a net-work across the whole surface of the planet, but faint and very difficult to see. (Fig. 72.) Their lengths vary from 350 to 4,000 miles, and their breadth is uniform all along their course, being from 20 to 60 miles across. More recent observations in Europe and America, specially by Mr. Lowell and M. Perrotin now fully confirm the existence of these "canals." In 1881, Schiaparelli

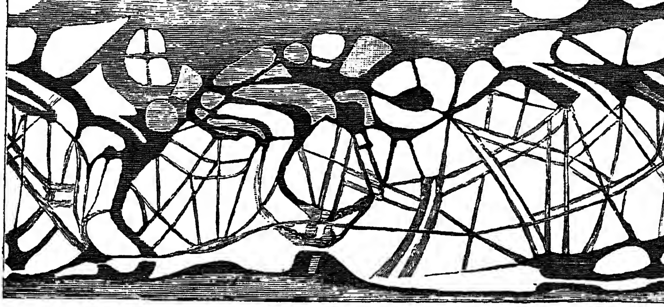


Fig. 72.—The Canals of Mars.

parallel lines of rail. Schiaparelli observed them only on the land portion, but it is now found that such a net-work of canals runs also over the "seas," which shows that it is absurd to regard the latter as bodies of water.

There is a wide difference of opinion among astronomers as to their *real nature and purpose*. Mr. Lowell says that the lines which we see are not the canals themselves, but streaks of vegetation growing on the banks by the supply of water brought down by them to the tropics, owing to the melting of the polar snow in spring. He believes that, as these canals are so straight, long and symmetrical, they are of *artificial* formation, and that their office is to irrigate the ruddy deserts. The dark circular spots seen at the junctions of the canals, and called "lakes," are interpreted by him as "Oases." No satisfactory explanation has been given about the "double canals."

120. Atmosphere. Mars has a very thin atmosphere. Its presence is proved by the following facts :—

1. Clouds are seen forming and dissolving, and without an atmosphere clouds cannot be formed.

2. Spectroscopic examination shows the presence of water-vapour on Mars, which is also an evidence of the existence of an atmosphere.

121. Phases and apparent size. Mars, being an exterior planet, does not show all the phases. At most times it appears full, and gibbous only at quadratures.

As the distance of Mars from us varies, its apparent size also varies. When it is in opposition, it is 48 millions of miles from us (141 — 93); but when in conjunction, we are 234 millions of miles from it (141 + 93). Hence its size in these two positions is as 234 : 48, *i.e.*, nearly 5 : 1.

122. Satellites. Mars has two satellites, which were discovered by Professor Hall in 1877. They are named Deimos and Phobos. These moons are the smallest heavenly bodies yet known, having diameters of hardly ten miles. "Their discovery was as great a feat of telescopic vision as for a man in Boston to see a tennis-ball at Philadelphia." Phobos revolves round Mars in 7 hrs. 39 min., or less than $\frac{1}{3}$ of the time of rotation of its primary, so it rises in the west and sets in the east, as seen from the planet. This is the only satellite in the solar system that *revolves more rapidly than its primary rotates*.

123. Is Mars habitable?

Though astronomers like Lowell, who have made careful observations of the surface of Mars, especially of the canals, maintain that there are rational living beings on the planet, one cannot answer this question better than in the word of Young, who says "While the conditions on ars are certainly very different from those prevailing on the earth, the differe_ce is less than in the case of any other heavenly body which we can see with our present means of observation; and if life, such as we know life on the earth, cau exist upon any of them, Mars is the place. But there is at present no scientific ground for belief one way or the other as to the habitability of other worlds than ours."

THE ASTEROIDS.

124. The asteroids (Gr. *aster*, star, and *eidos*, like) are otherwise called *minor planets* or *planetoids*. They revolve round the sun between the orbits of Mars and Jupiter in very close orbits.

125. Number and size. They are over 600 in number, but are barely visible to the naked eye. The *largest* of them, Ceres, is about 485 miles in diameter, and the smallest 10 miles. Indeed, the combined mass of all the asteroids is perhaps less than $\frac{1}{100}$ that of the earth. "Compared with the earth they are as flour-dust to a foot-ball." Their diameters are found out from the amount of light they reflect. The *brightest* is Vesta—the only one visible to the naked eye under favourable conditions.

126. History of their discovery.

In 1778, Bode drew attention to a curious law, first noticed by Titius in 1772, but usually called "*Bode's Law.*" If we write down the numbers 0 3 6 12 24 48 96, and add 4 to each of them, we get 4 7 10 16 28 52 100. These new numbers, with the exception of the fifth, fairly represent the relative distances of the planets then known from the sun. But the number 28 in the series corresponded to no known planet, so astronomers believed that there was a planet undiscovered which would fill the gap. In 1781, after the discovery of Uranus, whose relative distance from the sun was found to correspond with the number 196 in the series, an association of astronomers was formed to search the Zodiac for the missing planet. But their attempts were without success. Piazzi, who was not a member of the association, however, carried off the honour of the discovery He discovered the first asteroid, *Ceres*, on 1st January 1801. The next three, *Pallas*, *Juno*, and *Vesta*, were discovered in 1802, 1804 and 1807 respectively by other observers. Between 1807 and 1845 there were no further discoveries; but immediately afterwards, the pace quickened, and the family of these little planets has increased very rapidly by photographic methods. Until 1891 they were discovered by comparing the bodies visible near the ecliptic with star-charts. But in that year a new epoch began, when Dr. Wolf first discovered an asteroid by *photography*. Upto now over 600 have been discovered, and one or two more are being found out almost every year.

Eros, recently discovered (in 1898), has a very remarkable peculiarity. Its mean distance is between the mean distances of earth and Mars, being 135,500,000 miles. But its orbit is highly eccentric, so that on rare occasions

it *approaches nearer to us than any other planet,* being then only $13\frac{1}{2}$ millions of miles from the earth, and thus affords a splendid opportunity for determining the sun's distance. The last favourable opportunity was in the winter of 1900-01. Another very remarkable thing observed about Eros for some months in 1901 was the *periodical variation in its brightness.* It is probably due to its axial rotation.

A new asteroid, TG, was discovered in 1906, which is as interesting as Eros. It is remarkable for its very *large mean distance,* which is almost the same as that of Jupiter, and as its orbit is highly eccentric, sometimes it goes *far outside Jupiter's orbit.*

127. Designation. Some of the asteroids are designated by names, and others more recently discovered by numbers enclosed in circles, thus (27). These numbers are given in the order of discovery.

128. Origin. Two theories have been suggested to explain the origin of the asteroids. (1) Dr. Olbers started the hypothesis that they are the fragments of a planet, which once existed between Mars and Jupiter, but which was broken up by a series of explosions, first of the body itself, and then of the pieces. But this hypothesis is now rejected from certain mechanical reasons.

(2) The view which is now accepted by most astronomers is that they are the diffused materials of a ring, which (according to the nebular hypothesis) ought to have formed a planet, but failed to do so, as the powerful attraction exerted on it by its neighbour, the giant Jupiter, is believed to have torn the ring to pieces and thus prevented its condensation into a planet.

JUPITER.

129. Distance, size, mass, density. The mean distance of Jupiter from the sun is 483 millions of miles. It is the giant planet of the solar system, being about 1,300

130. Revolution and rotation. Its periodic time is 11·86 years. It rotates on its axis in only 9 hours 54 minutes, so its equatorial velocity must be about 30,000 miles an hour! This is tremendous swiftness for a huge body like Jupiter.

131. Appearance to the naked eye. To the naked eye, Jupiter is an excessively brilliant object, and in this respect it is surpassed only by Venus. It can be distinguished from Venus by the fact that Venus can be seen only near the sun and never at midnight; whereas Jupiter is visible even at midnight.

132. Telescopic appearance. When observed through a telescope, Jupiter appears of a distinctly oval shape, very much flattened at its poles. This may be due to its immense velocity of rotation.

Its surface is crossed by dark belts parallel to the equator. (Fig. 73.) In larger telescopes they look reddish. These belts are, however, not permanent; they change from time to time. But sometimes a marking is observed which remains unchanged for a long time. One such was first seen in 1878 and is still visible, though it has become extremely faint and slightly changed in form. It is called the "*Great Red Spot*" of Jupiter. The nature of the spot has not been satisfactorily explained. The dark belts are supposed to be openings in the clouds, through which we see the darker surface of the planet or the layers of clouds below. Besides the belts, sometimes bright as well as dark *spots*, usually round or elliptical, are seen, which have enabled us to determine the rotation-period of the planet. The spots at the equator, however, travel faster than those remote from it. Probably they are masses of clouds above the general surface.

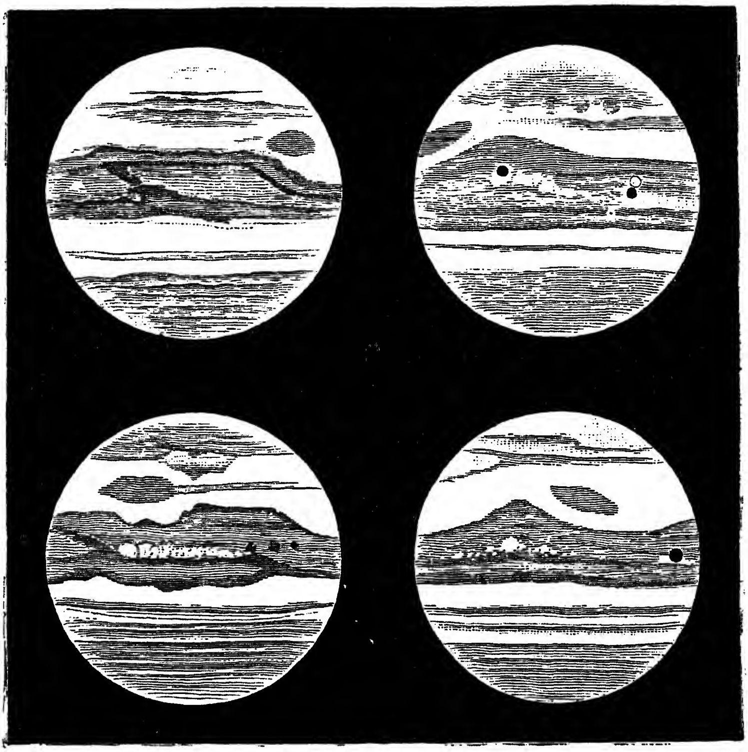


Fig. 73.—Telescopic Views of Jupiter, showing the Transit of Satellites across its Disc, and the "Great Red Spot."

power) is probably due to these clouds.

134. Physical condition and Temperature. The low density, excessive cloudiness, and the constant relative motions in the surface of the planet show that Jupiter must still be largely gaseous and very hot. It is, perhaps, yet a "ball of fluid overlaid with clouds and vapour." But as it gets very little heat from the sun, it must be *hot on its own account* like the sun. In fact, it may be regarded as a "semi-sun," though not self-luminous. The spectroscope shows the presence of water-vapour.

135. Satellites. Jupiter has 7 satellites revolving round it, all at different distances from the planet. Four of them are large and nearly of the same size, of which the largest is about as big as Mars. These four are all visible in a good opera-glass. They were discovered by Galileo in 1610. The fifth, which is an extremely tiny object, was discovered by Barnard in 1892 very close to the planet. The sixth and the seventh were discovered by Perrine in 1905 by photography. They revolve round Jupiter from west to east (except possibly the seventh, which seems to move retrograde), and show phases like our moon. Their orbits, except those of the sixth and the seventh, are but slightly inclined to the plane of Jupiter's orbit, consequently they show the phenomena of eclipses and transits at every revolution, and of occultations at sometimes. (Fig. 74.)

Eclipses of satellites. The shadow thrown by Jupiter is so extensive that at every opposition the satellites are eclipsed (except the fourth). In Fig. 74, the satellite A is eclipsed. These lunar eclipses cannot always be seen by us. If the planet is at conjunction or opposition, we cannot see the eclipse at all. When the planet is near quadrature, *i.e.*, if the earth is at E′, the whole eclipse occurs quite clear of the

disc, and we can see both the disappearance and the reappearance of the satellite. These eclipses are carefully watched by mariners, as they enable them to determine the longitude at sea. (*Cf.* Art. 210.) They are also useful as affording us the means of finding the time taken by light to travel from the sun to the earth , hence also the distance between the earth and the sun. (*Cf.* Art. 224.)

Transits. When a Jupiter's satellite comes directly between the earth and Jupiter, it appears to cross the planet's disc, and is in *transit*. Satellite C in Fig. 74 is in transit

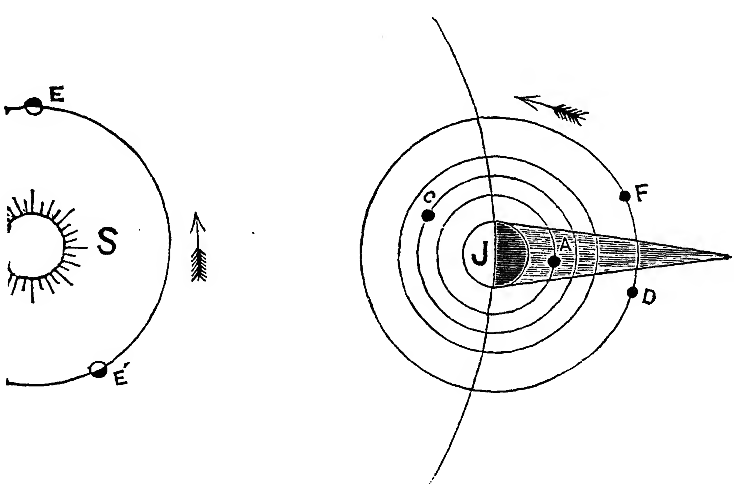


Fig. 74.—Eclipses, Transits and Occultations of Jupiter's Satellites.
A is eclipsed, C is transited, D is occulted as seen from E, or is occulted at F as seen from E′.

as seen from the earth at E. The transit may either be bright or dark. The edges of Jupiter are darker than the centre ; so, if a satellite comes to the edge, it is visible as a *bright* spot on the dark back-ground of the planet. If the back-ground is immensely bright, the satellite appears like a *dark* spot during transit. When the satellite crosses a portion of the disc as

Occultations. A Jupiter's moon sometimes becomes invisible to us, because it passes behind the disc of the planet, but not through its shadow. Then the satellite is said to be '*occulted.*' In Fig. 74, satellite D is occulted as seen from the earth at E. At times, the earth is in such a position that the occultation of the moon takes place just *before* its eclipse, as when the earth is at E. (Fig. 74, D.) In such a case we do not see the beginning of the eclipse. At other times the occultation occurs just *after* the eclipse, as when the earth is at E′. Then we cannot see the *ending* of the eclipse. (Fig. 74, F.)

SATURN.

136. **Distance and diameter.** The mean distance of Saturn from the sun is 886 millions of miles. Its diameter is 73,000 miles.

137. **Revolution and rotation.** It revolves round the sun in $29\frac{1}{2}$ years, and rotates on its axis in about $10\frac{1}{4}$ hours.

138. **Density.** Its density is less than that of water. It is composed of materials the *least dense* among the planets. In fact it is so light that it would float on water. We, therefore, conclude that, like Jupiter, Saturn is largely gaseous.

139. **Appearance with the naked eye.** To the naked eye, Saturn appears of a distinctly yellowish colour, and is as bright as a star of the first magnitude.

140. **Telescopic appearance.** Saturn presents a truly grand sight in the telescope. It is one of the most interesting celestial objects, and when once seen can never be forgotten. Besides being attended by ten satellites, its globe is seen surrounded by a marvellous system of rings, which is quite unique among the heavenly bodies. (Fig. 75.)

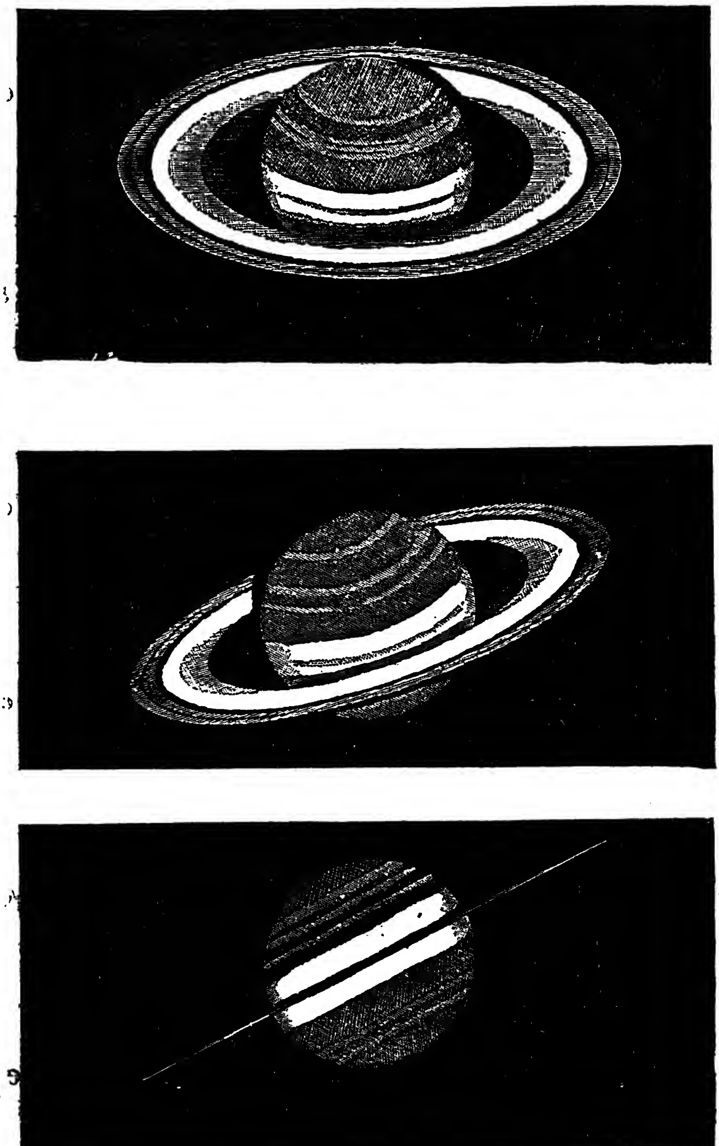


Fig. 75.—Telescopic Views of Saturn and its Rings.

change. Just at the pole there is a cap of olive-green.

141. Physical condition. Like Jupiter, Saturn is surrounded by an atmosphere, full of clouds which are formed by its interior heat. It must be still largely vaporous and very hot, but not so hot as Jupiter. On the whole, Saturn resembles Jupiter very much in its physical constitution.

142. Rings. The ring-system of Saturn is its most remarkable peculiarity. The globe is surrounded by three, thin, flat, concentric rings of various colours. (Fig. 75.) The innermost, called the *crape or dusky ring*, is of a purple colour and semi-transparent, so that the globe of the planet may be seen through it. The middle one is the broadest of all, and its outer portion is the brightest part of the whole ring-system, being quite as bright as the planet itself. The empty space between the two outer ones is called "*Cassini's Division.*" There is also a finer division in the outermost ring itself; it is named "*Encke's Division.*" The outer edge of each ring is brighter than the inner one.

Dimensions. The greatest diameter of the ring-system is 173,000 miles, and its breadth 42,000 miles.

Thickness and structure. The thickness of the rings is not uniform, and is extremely small, probably less than 50 miles.

They are not bright continuous sheets, solid or liquid, but closely packed swarms of extremely minute satellites or meteors, revolving round the planet in the plane of its equator, each in its independent orbit. In the dark ring, these bodies are not so closely packed, hence its semi-transparency. This view was confirmed by the spectroscopic observations of Keeler in 1895.

Phases. The plane of the rings coincides with the plane of the planet's equator, and remains parallel to itself at all times. But they are inclined 28° to the plane of the ecliptic; therefore, during the revolution of Saturn round the sun, the

rings show phases to us. They sometimes appear edgewise, sometimes full-face. Twice in 29½ years, they will appear edgewise to the earth or the sun. Att hese times, they can hardly be seen owing to their thinness, except in the largest telescopes. Then they look like a fine needle of light piercing the planet's globe. (Fig. 75.) The rings last disappeared in July 1907.

Their discovery.

It may be said that Galileo half-discovered the rings in 1610, when he saw with his telescope two "ears" or "handles," one on each side of the planet; but he could not explain them, and after a time they disappeared. The true nature of the rings was explained in 1655 by Huyghens, a Dutch astronomer, who announced it in the form of an anagram in Latin.

143. Satellites. Saturn is attended by 10 satellites, of which the last was discovered in 1905. The ninth is so minute that it was discovered by photography; but Barnard has *seen* it now with the Yerkes telescope. It revolves round the planet in the retrograde direction.

URANUS.

144. Discovery. Including the earth, the number of planets known to the ancients was six, Saturn being the most remote. Uranus was the first planet which may be said to have been ever *discovered*. It was found accidentally by Sir William Herschel in 1781, while "sweeping" the heavens for interesting objects with a telescope made by himself.

145. Distance, diameter and density. The distance of Uranus from the sun is 1,782, 000,000 miles. Its diameter is 35,000 miles. The density of the planet is about ⅕ that of the earth.

146. Revolution and rotation. Its periodic time is 84 years. Its rotation-time is about 10 or 12 hours.

147. Appearance. To the naked eye, it appears like a star of the sixth magnitude. In the telescope, its disc shows a greenish colour marked by faint belts not parallel to

SIR WILLIAM HERSCHEL (1738-1822.)

of its physical condition. It is supposed that it has a dense cloudy atmosphere like Jupiter and Saturn.

149. **Satellites.** Uranus has 4 satellites. Their orbits lie in a plane which is almost perpendicular to the plane of Uranus's orbit. They also revolve round the planet from *east to west*, and thus form an exception to the general law of planetary motion.

NEPTUNE.

150. **Discovery.** The discovery of Neptune is regarded as the most remarkable triumph of mathematical astronomy. In 1820 some *perturbation, i.e.*, deviation from the computed orbit, was first noticed by astronomers in the motion of Uranus, which could not be accounted for. But it was suggested that there was possibly some unknown body outside its orbit, whose attraction was displacing Uranus from its calculated path. By 1845 this discrepancy between theory and observation became so great that two astronomers, Mr. Adams of Cambridge and M. Leverrier of France, set about to ascertain the position of this unknown planet independently. After most skilful and laborious calculations, Leverrier wrote to Dr. Galle of Berlin, who had a very good star-chart, asking him to direct his telescope to a particular point in the sky, and saying that he would find, within a degree of that point, a new planet as bright as a star of the ninth magnitude and having a perceptible disc. Galle did so, and on 23rd September 1846 found the planet almost exactly at the point Leverrier had indicated. Here were the position, mass, etc., of a planet calculated by its effect upon other bodies *before the planet had ever been seen!* No wonder, therefore, that the discovery is esteemed as one of the greatest triumphs of modern astronomy. It leaves no doubt about the

truth of Newton's theory of universal gravitation, upon which both these astronomers based their calculations.

151. Distance and diameter. The mean distance of Neptune from the sun is about 2,800 millions of miles. Its diameter is 33,000 miles.

152. Revolution and rotation. It takes 165 years to revolve round the sun. It has not yet made half a revolution since its discovery in 1846. The time of rotation is unknown.

153. Appearance. Neptune is invisible to the naked eye. Its disc appears of a greenish colour when observed through a large telescope. No markings have been noticed on its surface.

154. Satellite. It has one satellite which moves backwards from east to west.

155. Physical condition. Little is known about the physical condition of Neptune. Its density is $\frac{1}{4}$ that of the earth. It has probably a dense cloudy atmosphere like Jupiter and Saturn.

156. Common features of the planets.

(1) All the planets are globular bodies, shining by the reflected light of the sun.

(2) All the planets revolve round the sun from west to east, *i.e.*, contra-clockwise as seen from the north of the ecliptic.

(3) All the planets move in elliptical orbits, having the sun at one of the foci.

(4) The orbits of all the planets are nearly in the same plane.

(5) All the planets rotate on their axes from west to east.

These common characteristics of the planets suggest a common origin, which is explained, as we shall see in Art. 202, by the Nebular Hypothesis.

157. Intra-Mercurian planets.

Some perturbations observed in Mercury's orbit have suggested the idea that there are perhaps small planets undiscovered inside its orbit, and some

Neptune has not been observed sufficiently long to detect perturbations in its orbit, so it is impossible to say whether there are any planets beyond Neptune. But if there be any such planet, it is sure to be discovered as a result of the preparation of *photographic star-charts* now almost completed.

159. The Zodiacal Light. In spring after sunset, and in autumn before sunrise, a faint mass of light in the shape of a slanting cone or wedge is seen tapering upward from the horizon along the ecliptic to nearly 98° from the point where the sun has set or rises. This is called the "*Zodiacal Light.*" (Fig. 76.) It can be seen only with the naked eye, because the field of a telescope is too small to enable us to contrast it with the dark sky. It is invisible in full moon-light. In tropical countries, as the ecliptic always stands high above the horizon, the zodiacal light can be well seen in a clear sky all round the year.

Two theories have been proposed as to its nature. The one that is generally accepted is that it is only the light reflected by an immense number of meteors revolving round the sun in the plane of the ecliptic. This belt of meteors seems to be densest near the sun.

The other theory is that it is an extension of the solar corona, a sort of reservoir into which the "waste matter" of the sun is flung in the form of particles through the streamers of the corona. The most recent view about these particles is that they are "corpuscles" (particles minuter than atoms) bombarded by the sun by means of the mechanical pressure of light.

160. The Gegenschein. The "*Gegenschein*" (German for "counter-glow") is an oval faint patch of light seen on the ecliptic directly opposite to the sun. It was discovered in 1854. Its theory is that, like the zodiacal light, it is the light reflected from an immense number of meteors. It can be seen only with the naked eye.

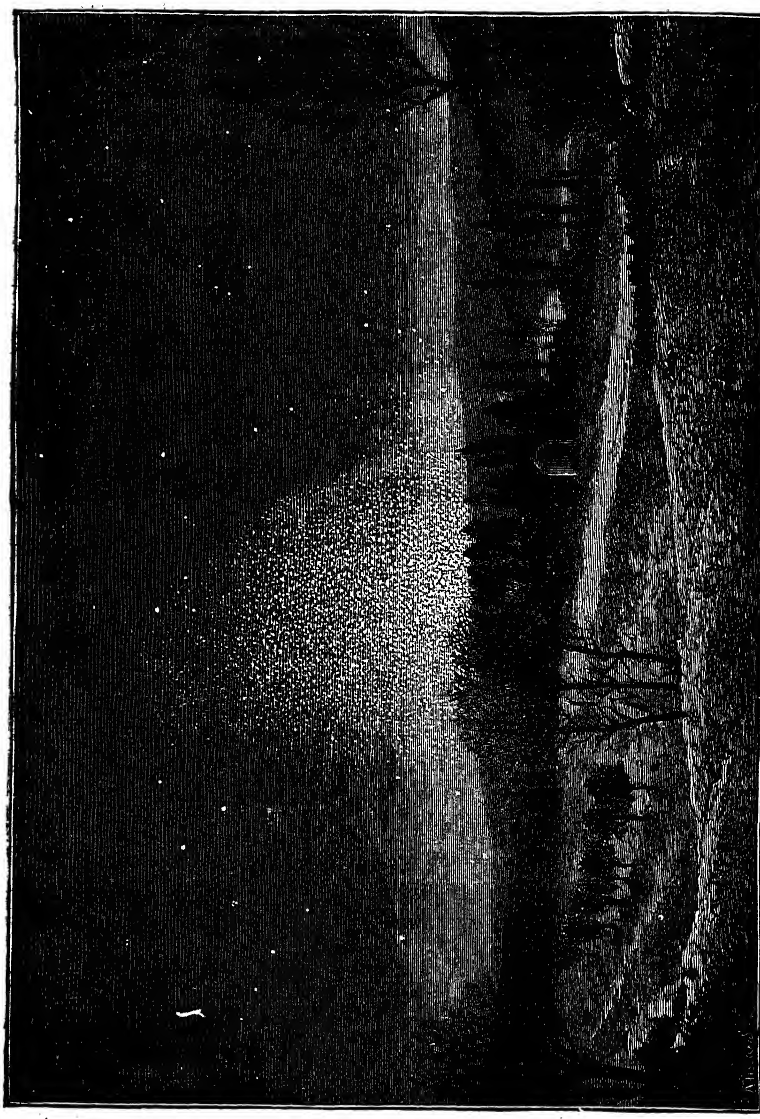


Fig. 76.—The Zodiacal Light in 1874.

COMPARATIVE TABLE OF PLANETS.

	Distance from sun in millions of miles.	Diameter in miles.	Period of revolution.	Period of rotation.	Density.
Sun		866,000		$25\frac{1}{3}$ days	0·25
Mercury	36	2,800	88 days.	88 days	0·67
Venus	67	7,800	225 days.	225 days	0·88
Earth	93	7,918	365 days.	24 hours	1·0
Mars	141	4,300	687 days.	$24\frac{1}{2}$ hours	0·72
Asteroids...........	257	10 to 500	4·6 years.	?	?
Jupiter...............	483	88,000	11·86 ,,	9 hrs. 54 min.	0·24
Saturn	886	73,000	29·5 ,,	$10\frac{1}{4}$ hours	0·13
Uranus...............	1782	35,000	84 ,,	10 ,,	0·22
Neptune	2791	33,000	165 ,,	?	0·20
Moon		2,163		27 ds. 7 hrs. 43 min.	0·61

CHAPTER XII.

COMETS.

161. Comets are strange heavenly bodies, looking very different from the planets. They make their appearance quite unexpectedly, remain visible for a few days or months, and vanish as suddenly as they appear.

162. Appearance and constituent parts. Comets vary so much in appearance, size and brightness that

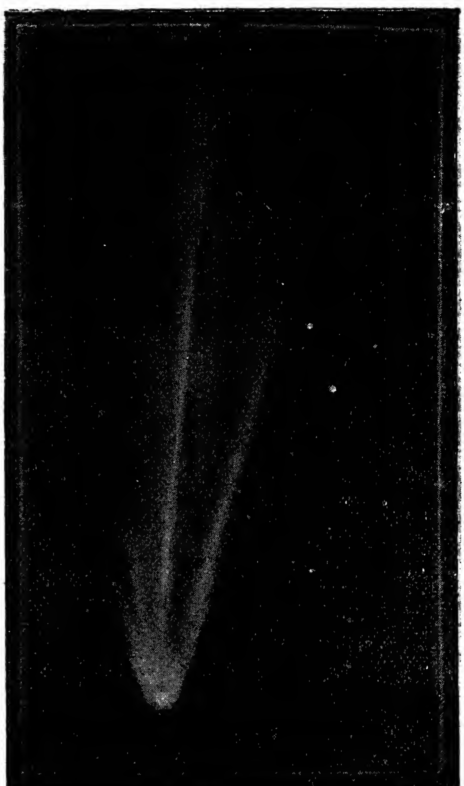


Fig. 77.—Comet *b*, 1881.
(Photographed by Janssen.)

no two are exactly alike. A large comet, however, usually

is the *nucleus*, which, however, appears only when the comet is near the sun. The *tail* is the dimmer part flowing from the head of some comets like a long train. (Fig. 77.) Only the larger comets have tails. The distinguishing part of a comet, which is always present, is the *coma*. The majority of comets are invisible to the naked eye. However, some are so large and brilliant that they can be seen in broad daylight, though they may be close to the sun. Such comets are, however, rare.

163. Changes in appearance. A comet undergoes many changes as it revolves round the sun. When it is

Fig. 78—Head and Envelopes of a Comet.

far away from the sun, it appears like a small nebula, having no tail. But as it approaches the sun, it gets brighter. Then the nucleus is formed, which, in brilliant comets, also sends forth spirts and clouds of luminous matter towards the sun. These are called "*Jets and Envelopes.*" (Fig. 78.) But the sun, by

virtue of some force of repulsion, throws them back. Thus the tail arises, which increases in length and splendour as the comet comes nearer to the sun, and diminishes as it recedes from it. (Fig. 79.)

Very recently it has been suggested that the force that repels the luminous matter away from the sun may be the *mechanical pressure* of the light of the sun.

164. The tail of a comet. The tail is the most prominent part of a comet. It may be long or short, straight or curved, or like a half-opened fan. Some comets have more than one tail. The tails of some comets are so long that they reach from the sun to the earth. The tail is composed of matter which is first emitted from the nucleus towards the sun and then repelled by the sun. It is so transparent that most stars are easily seen through it, without losing the smallest amount of light.

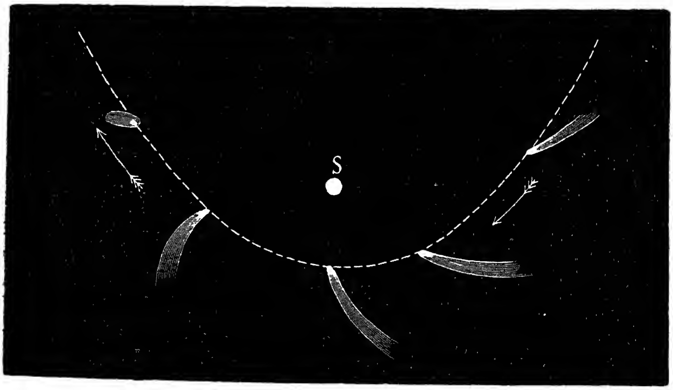


Fig. 79.—Changes in the Appearance of a Comet

As the tail is repelled by the sun, it always *follows* the comet as it approaches the sun, but *precedes* it when it goes away from the sun, so the ancients then called it the *beard*. (Fig. 79.)

165. Volumes and masses of comets. Though the volumes of comets are immense, their masses are extremely small, probably not more than $\frac{1}{1,000,000}$ that of the

in the motion of a planet as they revolve round the sun. It is, however, observed that the planet is not at all disturbed. On the contrary, the comets themselves are compelled to change their orbits. For example, Brooks' comet passed through the satellite-system of Jupiter in 1886 without sensibly disturbing their motions; but its own orbit was changed, having been reduced from 27 years to 7 years.

166. Orbits of comets. (1) The orbits of some comets are highly eccentric ellipses, that is, they approach very close to the sun at one time and then go away from it to immense distances. Some comets have their perihelion points actually *within the corona of the sun.* Most comets have unclosed orbits, called parabolic orbits. The orbits of about 400 comets have been computed upto 1901, and it has been found that more than 300 of them are parabolic. Of the remaining, about 90 have elliptical orbits, and 6 or 8 slightly hyperbolic. (*Cf.* Fig. 25.) Parabolic or hyperbolic comets, after once passing the sun, never return. They may be regarded as visitors to the solar system. Those that move in elliptical orbits are regular members of the system just like the planets, and return at regular intervals; hence they are called "*Periodic Comets.*" Comets that have periods ranging from 3 to 8 years are called "*Short-period Comets.*"

(2) The orbits of comets have very great inclinations with the plane of the ecliptic. Some cometary orbits are inclined as much as 90° to the ecliptic.

(3) With two exceptions, all the comets that move in elliptical orbits in periods less than 100 years do so from west to east. Of the other comets, some revolve round the sun from east to west, that is, they have a retrograde motion, and the rest have a direct motion.

167. Designations and number. The larger comets are named after their discoverers, *e.g.*, Donati's Comet, Halley's Comet,* Encke's Comet, Biela's Comet, Brooks' Comet, etc. Others are named by the year of their discovery, to which the letters *a*, *b*, *c*, etc., are prefixed, thus "comet *f*, 1858." About 800 comets have been recorded during the last three thousand years. Before the telescope was invented, very few were observed. At present every year about half a dozen are found; but the majority of them are too faint to be seen with the naked eye. A really brilliant comet last seen appeared in 1882. Kepler said that comets were as numerous as fishes in the sea.

168. "Capture theory." Most of the short-period comets seem to be intimately connected with Jupiter, Saturn, Uranus or Neptune. Hence they are otherwise called "*Planetary Comets*," or "*Comet-Families*." The nature of the connection is explained by the "*Capture Theory*." According to this theory, these comets once did not belong to the solar system, though they revolved round the sun in parabolic orbits. But on their way to our luminary, whilst they were rushing past these major planets, specially Jupiter, their paths were disturbed, on account of the strong pull exerted on them by these planets. Their motions were thereby *retarded*, and they were, consequently, compelled to move round the sun in elliptical orbits. In other words, they were "*captured*" by these large planets, and added to the solar system.

169. Constitution of a comet. The most probable theory as to the constitution of a comet is that its head consists of a swarm of small meteoric solid bodies scattered about, and that each particle is enveloped by rare gases, in which light is produced mostly of electric origin. The nucleus is believed to be the densest portion of such a swarm of meteors.

* Halley's Comet is expected to return in 1910.

partly by the reflected light of the sun.

171. Chemical composition. The spectroscope reveals the presence of carbon, hydrogen, sodium, iron and nitrogen in comets.

172. Superstitions about comets.

In former times the appearance of a comet was regarded with superstitious dread, as foreboding some calamity or grief to mankind. The following lines were written when the comet of 1618 appeared: —

"Eight things there be a comet brings,
When it on high doth horrid range;
Wind, Famine, Plague, and Death to Kings,
War, Earthquakes, Floods and Direful change."

White in his "History of the Doctrine of Comets" says that these lines were to be taught seriously to peasants and school children! Though now this dread has to a great extent disappeared from the popular mind, still it is feared that, if a comet actually came into collision with our earth, the consequences would be terrible. Such an occurrence *is* possible, but the nature of the effects will depend upon the size of the particles which form the head of the comet. If they weigh *tons*, the earth would certainly receive very hard knocks; but if, as is more likely, they are "smaller than pinheads," the result would be merely a meteoric shower, which an astronomer would behold with delight and admiration. The earth actually passed through the tail of the comet of 1861, without having been any the worse for the encounter.

CHAPTER XIII.

METEORS.

173. Shooting stars. On any clear moonless night bright star-like points may be seen shooting rapidly across the sky, leaving a luminous streak for a second or two behind. These are called "*Shooting Stars.*" The bright ones generally leave trains which last from 5 to 10 minutes.

174. Meteorites. Rarely, larger masses, after rushing through our atmosphere, actually fall to the ground. They first appear at altitudes of 60 to 100 miles, and move over paths 50 to 500 miles long at the rate of 10 to 40 miles per second. These are known as *meteorites* or *aerolites*. When they fall at night, they look like balls of fire, generally followed by a luminous train, which remains visible for a few minutes. They are sometimes as large and bright as Jupiter or even the moon. Their flight is usually accompanied by a "heavy continuous roar," and sometimes by violent detonations, which are frequently heard 50 miles away. Their weights have ranged from a few grains to 700 lbs.

On examining those meteorites which have fallen to the earth, the majority are found to be *stony*; very few are *metallic*. The latter consist of nearly pure iron alloyed with nickel. The outside of meteorites is covered with a thin black crust, usually glossy like varnish. Twenty-seven chemical elements, including argon and helium, have been found in them.

The total number of meteorites which have been collected since 1800 in different parts of the world is about 275.* The actual number that strike the earth is probably 100 a year, though the number of those that have been seen to fall is only from 2 to 6 each year.

Both shooting stars and meteorites are called *meteors*.

* The finest collection of meteorites in the world is that at Vienna.

they strike our atmosphere), revolving round the sun in vast swarms in highly elliptical orbits. These orbits are so numerous that they intersect the orbit of the earth at almost every point of it. When the earth comes at any point of intersection, a collision takes place between the earth's atmosphere and the meteors. The sudden checking of their velocity produces so much heat that they begin to glow, and thus become conspicuous. The smaller ones—the shooting stars—are consumed before they reach the earth. The larger ones—the meteorites—reach the earth very much reduced in size. The products of their combustion, which are in a very finely divided state, remain suspended in the air for a short time, and ultimately fall imperceptibly to the ground.

176. Number and periodicity of shooting stars. It is computed that between 10 and 20 million visible meteors enter our atmosphere every 24 hours, of which an experienced observer can see 14 every night. But, if we include those that can only be seen through a telescope, the number comes to be 120 millions.

On certain nights in the year, an unusual number of shooting stars is seen. Then we are said to have a "*meteoric shower*." They seem to come from particular points in the sky, known as the '*radiants*,' because the meteors all appear to *radiate* from them. On August 10, they come from the constellation of Perseus, and are called *Perseids*. On November 15, others apparently come from Leo, and are, therefore, known as *Leonids*. Meteoric showers also come from Andromeda on 24th November, and are called *Andromids*. They moreover appear in unusual numbers every 13 years. The Leonids and the Andromids are the most conspicuous showers; amongst the other less conspicuous ones, the *Lyrids* appear on

April 20, the *Orionids* on October 20 and the *Geminids* on December 10.

Explanation of periodicity. The earth's orbit cuts the orbits of some swarms of meteors, which encounter the earth at the points of intersection in particular months. Hence we have an unusually larger number of meteors in these months.

177. The $33\frac{1}{4}$-years' shower of Leonids. One of the swarms of meteors in the Leonids is very large, and completes its revolution round the sun in $33\frac{1}{4}$ years. When the earth meets this swarm in November, we get a great shower of shooting stars. (Fig. 80). This takes place every $33\frac{1}{4}$ years at almost the same time of the month. The swarm is so long that, even when the earth returns to its original position after having finished its revolution, it overtakes the *rear* of the procession, so next year also there is a similar great shower. The last two great showers of the Leonids were seen in 1833 and 1866, and less remarkable ones in 1898 and 1901.

178. Connection between comets and meteors. After the great Leonids-shower of 1866, it was found that the orbits of several of the swarms of meteors were identical with those of some of the comets. From this it appeared that there was a real and close connection between comets and meteors. Most astronomers now believe that *a comet is only the thickest part of a swarm of meteors, and that the diffuse ring of meteors scattered along its path results from the disintegration of the comet.* This disintegration is caused by the attraction of the sun or any major planet at every near approach of the comet to the sun or the planet. The following reasons are usually given for this belief :—

1. The shape, the size and the position of the orbits of some meteoric swarms are the same as those of some comets.

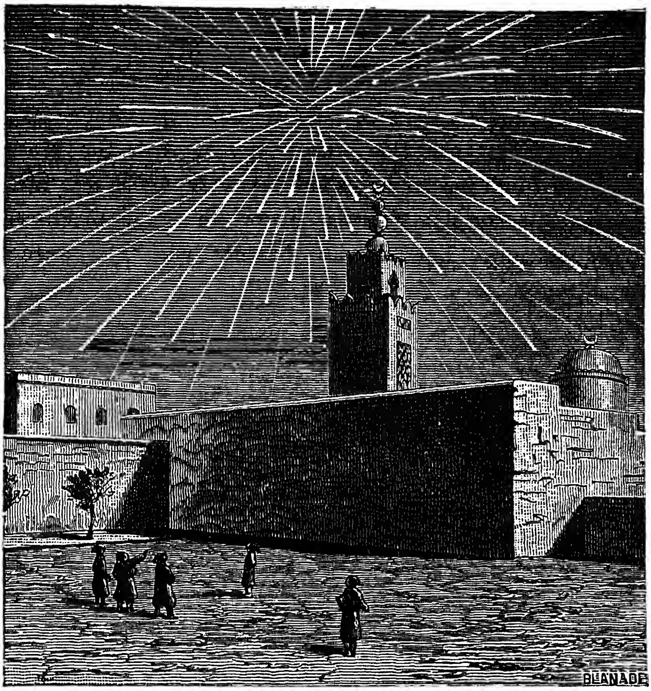


Fig. 80.—A Great Shower of Shooting Stars.

2. The light of a comet at a great distance from the sun, when analysed in a spectroscope, is found to have the same character as that of a meteorite when *gently* heated in a laboratory.

3. As a comet approaches the sun, its light undergoes changes. These changes and their order are exactly the same as those observed when the temperature of the meteorite is *raised* in the laboratory.

179. Lockyer's Meteoritic Hypothesis.—The astronomical importance of meteors has been largely increased within the last two decades by Sir Norman Lockyer. He maintains that *all the heavenly bodies are swarms of meteors*, more or less condensed, or the final products of such condensation. But this view has not yet been accepted by all astronomers.

180. Immediately surrounding the solar system, is an immense gap probably containing comets and meteors. Beyond this void is the starry firmament. The distance of the *nearest* star from us (Alpha Centauri) is more than 275,000 times greater than the distance between the earth and the sun. Seen from it, our sun would look like the pole-star.

181. Number of stars. The *number* of stars *visible to the naked eye* on a clear moonless night is between 5,000 and 6,000.* Of these, the smallest are of the sixth "magnitude." In the Yerkes telescope, 100,000,000 stars can be seen. Photography has come to the aid of the eye in recent years, the number of photographic stars being more than 500,000,000.

182. Brightness and colours. The stars are of various degrees of brightness. According to their degree of brightness, they are divided into eighteen classes called "*magnitudes.*" (The word "*magnitude*" here has nothing to do with the apparent angular diameter of a star—it refers only to its *brightness.*) The brightest stars are said to be of the "first magnitude." There are 20 such stars, of which Sirius (the Dog-star) is the brightest in the heavens. Stars upto the sixth magnitude are visible to the naked eye.

Experiments have shown that the light received from a first-magnitude star is about 100 times as much as that given by one of the sixth magnitude.

The brightness of a star depends upon three factors, (1) its distance, (2) its actual size, and (3) its inherent luminosity.

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* Stars which are visible to the naked eye are called "*lucid stars,*" to distinguish them from "*telescopic stars*" which can be seen only in a telescope.

The *colours* of the stars are various: white, blue, red, yellow, green, etc. Most stars are white; Sirius is a type of such stars. The colour of a star depends upon the *materials* of which it is composed, as well as upon its *temperature.*

183. Star-catalogues and star-charts. Stars can be recognised by a reference to "*star-catalogues.*" These are carefully prepared lists of stars usually above a certain degree of brightness, giving their positions at a given epoch and also their magnitudes. At present our catalogues contain 800,000 different stars.

For certain purposes a *star-chart* is more useful than a star-catalogue. Formerly such charts were made by dividing the sky into a number of zones and then plotting the results of the observations of stars in these zones; but at present they are made by photography. Astronomers in different parts of the world are now engaged in a co-operative scheme (begun in 1889) of preparing *a photographic chart* of all the stars down to the 14th magnitude. Most of the work, in which 18 observatories have participated, is now done, and, when completed, the plates will show about 15,000,000 such stars.

184. Distances of stars. The distances of stars are so stupendous that it would be inconvenient to express them in miles, or even in terms of the usual astronomical unit of distance—the radius of the earth's orbit. To estimate such vast distances, astronomers use, as a unit, what is called a "*light-year.*" It is the distance travelled by light in one year. The velocity of light being 186,000 miles a second, a "light-year" consists of $186{,}000 \times 365 \times 24 \times 60 \times 60$ miles. The distance of the nearest star—Alpha Centauri in the southern heavens—is found to be more than 4 such "light-years." A great majority of the stars are so distant from us that their light takes more than 100 *years* to reach us, and some stars may

Stellar distances are found out by measuring the *parallaxes* of stars by certain methods.* The parallaxes of about 45 stars have been determined with more or less accuracy.

185. Dimensions of stars. If the distance and apparent angular diameter of a heavenly body be known, we can determine its actual diameter in miles. The apparent diameters of planets can be found, because in the telescope they show *discs*; but the stars are so distant from us that, even in the best telescopes, they appear as mere *points of light*. Their angular diameters cannot, therefore, be determined by the best modern instruments; hence this method is inapplicable in the case of stars. However, recently, spectroscopic methods have been used to find out the dimensions of one or two binary stars, which have thus been found to be much larger than our sun.

186. Composition of stars. The spectroscope, by analysing the light of stars, tells us what substances are present in them. Sodium, magnesium, calcium, iron, hydrogen and helium have been detected. The same instrument has also shown that the stars are hot self-luminous bodies, consisting of glowing vapours like our sun. In short, the stars are "distant suns," but in various stages of evolution.

"One sun by day, by night ten thousand shine,"

as poet Young so truly says.

187. Star-light. The amount of light received by us from the stars is extremely small. Young says that the full-moon gives 60 times as much light as that received from the entire starry firmament on a clear moonless night.

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* *Vide* Art. 223 for the meaning of the term 'parallax.'

188. Apparent motions of stars. The stars have four apparent motions:—

(1) The apparent daily motion of the stars from *east to west*, caused by the rotation of the earth on its axis.

(2) The apparent yearly shift of the stars *westward*, due to the annual revolution of the earth round the sun.

(3) The apparent change in the positions of stars, occasioned by the change in the direction in which the poles of the earth point, giving rise to the "*precession of the equinoxes.*" (Art. 222.)

(4) It is found that the stars in a particular part of the sky appear, year after year, to *close up*. There are other stars in the opposite direction, which have a tendency to *open out*. This apparent closing up and opening out of stars is caused by the real motion of the sun with the solar system, at the rate of 11 miles a second, towards that part of the sky where the stars open out. The point to which the system is moving is located within 5° or 6° of the star Vega in the constellation of Lyra, very near the constellation of Hercules, and is called the "*apex of the sun's way.*"

These apparent motions are also called "*common*" motions because all stars in the same part of the sky partake of them alike.

189. Proper motions of stars. The stars are ordinarily called "fixed," because their relative positions and configurations have apparently remained unchanged for centuries; but this is not strictly true. Careful observations with our modern instruments of precision have shown that a large number of stars *really* move, with respect to each other, flying through space with velocities much greater than the speed of a cannon-ball. But their change of position is so small on account of their enormous distances that it is hardly perceptible, except by delicate measurements taken at long intervals. Such motions of stars are called "*Proper Motions,*" the word "proper" here meaning "their own."

Stars are now known to have proper motions in all possible directions at different rates, but always in a straight line. Lockyer says, "From mechanical reasons it is probable that *all* the stars are in motion." The largest proper motion of a star at present known is that of a little star of the eighth magnitude in the southern heavens, which drifts $8''.7$ yearly.

190. Variable stars. Some stars undergo a periodic change in their brightness. Such stars are called "*Variable.*" There are more than 300 of them, and the list is constantly increasing. *Mira* in the constellation of Ceti, *Beta Lyræ* and *Algol* in the constellation of Perseus are types of such stars.

In the case of Algol, the variation is caused by the partial *eclipse* of the star, due to the periodical interposition between us and the star of a dark opaque body—called "the dark companion"—which revolves round it.

191. Temporary stars are those which blaze up suddenly in parts of the sky where none was previously seen, and gradually fade away, until they become invisible. There are about 20 well-authenticated cases in which new stars have thus appeared temporarily.

Temporary stars are called *novæ*, or new stars, *e. g.*, Nova Cygni, Nova Aurigæ, etc. The most recent, and one of the most remarkable instances of a new star is that of Nova Persei, which first appeared on Feb. 20, 1901, and disappeared at the end of March.

192. Double stars. There are many cases in which two stars lie so close to each other that to the naked eye they appear as one star. The individual stars can be separated only in powerful telescopes. Such stars are called "*Double Stars.*" If the two stars are of the same degree of brightness, they have the same colour. But if they differ very much in brightness, the smaller star appears bluish. At present we know of about 12,000 such double stars, and new ones are being constantly discovered. *Castor, Beta Cygni, Gamma Andromeda, Mizar* in the Great Bear are examples of such double stars.

Double stars are of two kinds: "*Optical Double Stars*" and "*Physical Double Stars.*"

Optical double stars. Optical double stars are those, the components of which are *apparently* near each other, but not really. The one simply is behind the other in the line of sight as seen from the earth, though they may be very distant from each other.

Physical Couples. *Physical Couples* are such double stars as are really near each other, and have a common centre of motion, about which they revolve in elliptical orbits, in periods ranging from 5 to 1500 years. Stars thus physically connected are also called "*Binary Stars.*" It is probable that a very large proportion of double stars are binaries.

193. Multiple stars. Sometimes more than two stars are found physically connected with one another in one system. These are called "*Multiple Stars.*"

In *Epsilon Lyræ* we have a most beautiful quadruple system, consisting of two pairs. *Theta Orionis* is composed of 6 stars, not arranged in pairs.

194. Spectroscopic Binaries. Recently the *spectroscope* has enabled us to detect several double stars so near each other that no telescope can separate them. Such double stars are called *Spectroscopic Binaries*," of which 140 were known up to the beginning of 1905.

195. Constellations. From very early ages stars have been grouped, such groups being called "*Constellations.*" The ancients gave them fanciful names, taken from Greek and Roman mythology, from the vague resemblance of their forms to well-known objects and animals.

The number of constellations now recognised is 67, of which 48 have come down from Ptolemy, the others having been formed since 1600.

In each constellation, the stars are designated by letters of the Greek alphabet. The brightest star in a group is called alpha (α) of the constellation, the second brightest

is beta (β), and so on. When all the letters are used up, the stars are numbered 1, 2, 3, etc. Again about 60 of the brightest stars have also names of their own; thus a Canis Majoris is called *Sirius*, and a Orionis is named *Betelgeuse*, and a Tauri is termed *Aldebaran*, and so on.

The *Zodiac* is a belt encircling the sky and 16° wide (8° on each side o the ecliptic) to which the moon and the planets confine their wanderings. It is divided into 12 equal parts, each 30° long, called the "*Signs of the Zodiac.*" Their names are the same as those of the zodiacal constellations mentioned below.

Zodiacal Constellations are those which are situated along the Zodiac, and which the sun passes over in its yearly round. They are visible both in the northern and southern hemispheres of the earth. They are :—

1. Aries (the Ram,)
2. Taurus (the Bull.)
3. Gemini (the Twins.)
4. Cancer (the Crab.)
5. Leo (the Lion.)
6. Virgo (the Virgin.)
7. Libra (the Balance.)
8. Scorpio (the Scorpion.)
9. Sagittarius (the Archer.)
10. Capricornus (the Goat.)
11. Aquarius (the Water-bearer.)
12. Pisces (the Fish.)

The Northern Constellations are those which are visible north of the Zodiac. The constellations visible south of the Zodiac are called the **Southern Constellations.**

Some of the principal constellations, which should be studied with the help of a star-atlas or celestial globe, are :—

Ursa Major (The Great Bear)
Ursa Minor (The Little Bear)
Cassiopeia (The Lady's Chair)
Orion (The Hunter or the Giant)
Taurus (The Bull)
Canis Major (The Great Dog)
Canis Minor (The Little Dog)
Gemini (The Twins)
Leo (The Lion)
Andromeda
Aquila
Pegasus
Hercules
The Southern Cross.

196. The Milky Way or Galaxy. The Milky Way is an irregular band or zone of faint light, averaging about 20° wide, and stretching overhead in the sky like a magnificent arch. It surrounds the heavens in a great circle intersecting the ecliptic at two opposite points. It is not a continuous sheet of luminous matter. The telescope shows that it is composed of millions of small stars so closely packed

together as to appear like a luminous mass. Of the 100,000,000 stars visible through a telescope, more than 90,000,000 are in the Milky Way. It also contains numerous star-clusters, but very few nebulæ.

The Galaxy is not of uniform brightness. Dark rifts and gaps are visible in certain places; one patch in the constellation of Centaur is called the "Coal Sack." About one third of its length, the Milky Way is divided into two streams, roughly parallel to each other.

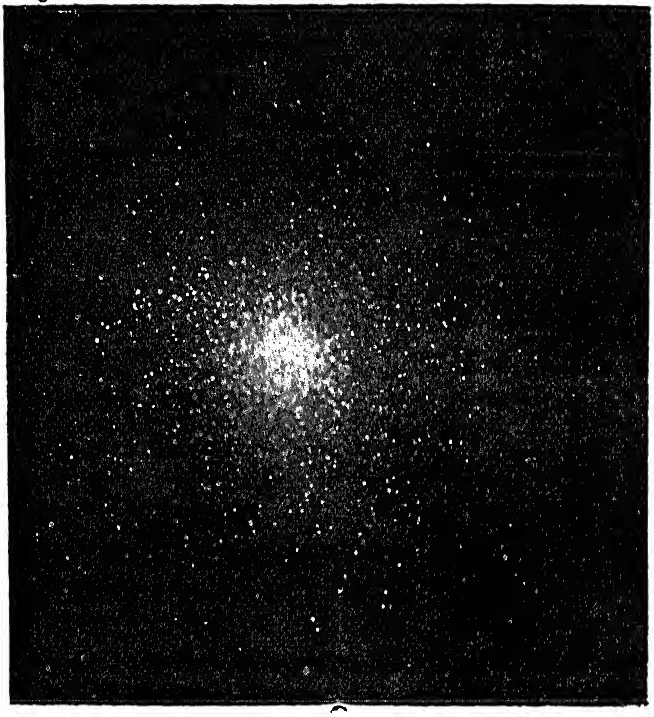


Fig. 81.—The Star-cluster in Hercules.

197. Clusters. Besides the stars scattered about in the sky and gathered together in the Milky Way, collections of stars are found containing hundreds or thousands of bright points. These are called "*clusters*." (Fig. 81.) In some the

separate stars can be seen with the naked eye, the best known being *Pleiades* in the constellation of Taurus ; but most of them can be resolved only in a large telescope. To the naked eye, they look simply like globular clouds of faint light, but in a large instrument they look splendid objects. The cluster in Hercules is the most beautiful in the northern sky, containing thousands of stars in a very small space. (Fig. 81) The clusters are found thickly strewn over the whole course of the Milky Way and along its margins.

Variable Star Clusters. Some clusters have recently been shown by photography to consist of a great number of *variable stars*. Upto now about 500 such clusters have been found.

CHAPTER XV.

THE NEBULÆ.

198. The nebulæ are cloud-like patches of foggy light scattered about the sky. They look like clusters, or comets when far away from the sun. But they can be distinguished from both. A cluster can be resolved into separate stars in a telescope; a nebula cannot be. A comet moves about in the sky; a nebula is fixed.

199. Shapes and classes of nebulæ. The *larger* nebulæ are generally of an irregular shape, containing many portions brighter than the other parts. Some of them are of immense volume. The Orion Nebula is the most beautiful of this class. (Fig. 82.) The *smaller* ones have a regular shape, more or less oval or circular, and brighter at the centre. They are called *planetary nebulæ,* because they resemble planets in their appearance.

Some nebulæ are ring-shaped, darker at the centre than at the edge, and are, therefore, called *annular nebulæ.*

A very large number of nebulæ have a spiral structure, like the hair-spring of a watch, as if they had a whirling motion. They are, consequently, termed *spiral nebulæ.* Of the thousands of nebulæ discovered recently by photography, a large proportion are spiral. In fact Keeler thought that the spiral is the normal type of nebulæ. The Great Nebula in Andromeda is a gigantic spiral. (Fig. 83).

In some nebulæ, the centre contains a bright star; such are known as "*nebulous stars.*" The stars may have been formed in them by the condensation of the central portion of the nebulous matter.

Fig.82.—The Great Nebula in Orion.

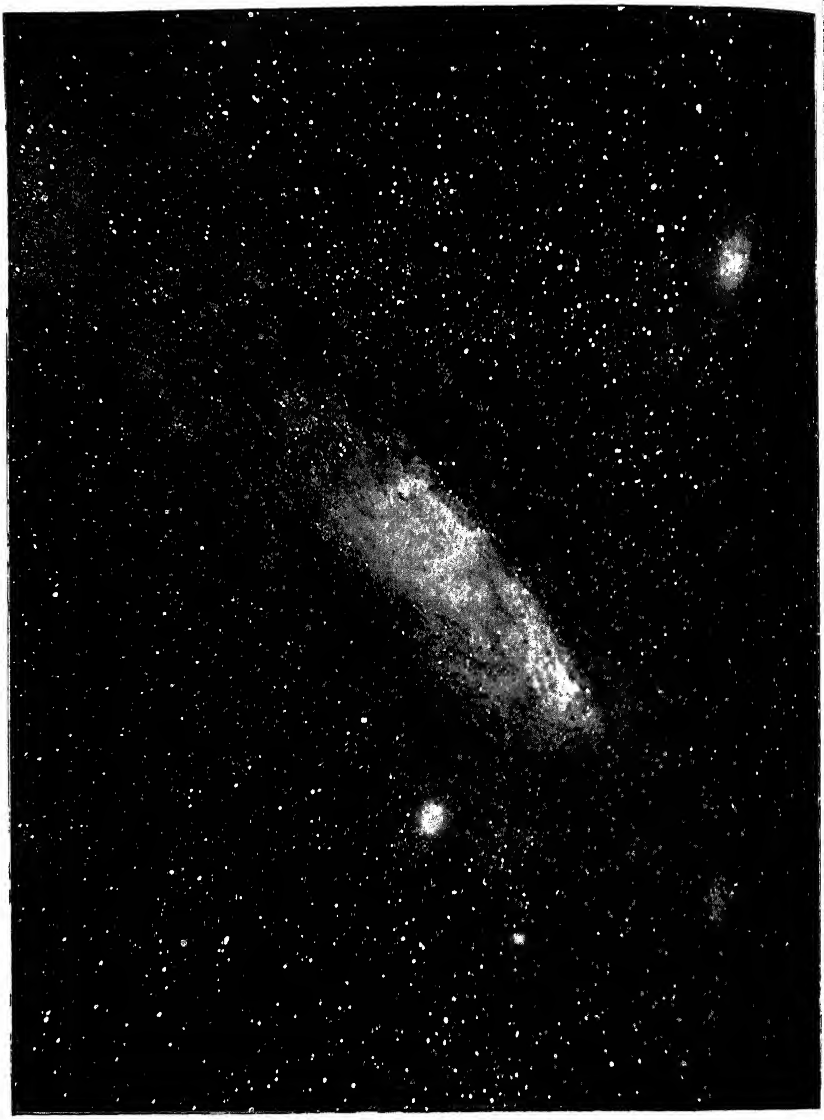


Fig. 83.—The Nebula in Andromeda.

200. Number and distribution. About 10,000 nebulæ are now catalogued ; but many more thousands have been discovered by photography, though most of them are very faint and uninteresting objects. About half a dozen only can be seen with the naked eye, of which the brightest are the Orion Nebula, and the Andromeda Nebula. The rest are visible only in telescopes.

The Nebulæ generally lie out of the Milky Way, where the stars are so crowded together.

201. Constitution. By analysing the light of a nebula in the spectroscope, we know that it is a mass of glowing *gas* of extreme tenuity. Hydrogen and helium have been detected in some nebulæ, and in others a substance unknown on the earth called *nebulium*. Lockyer, however, believes that a nebula is a swarm of sparse *meteorites* clashing together and producing heat, which makes them shine. The interspaces are filled with hydrogen and metallic vapours given out by the glowing meteorites.

202. The Nebular Hypothesis. To account for the origin and growth of the Solar System, La Place, a celebrated French astronomer, propounded a brilliant theory, which is called "*The Nebular Hypothesis.*" It is as follows :—

In very remote past there was a vast *nebula*, occupying the space now lying between the sun and the extreme limits of the Solar System. This nebula consisted of matter in a highly diffused gaseous state, at a high temperature, but not of uniform density. The mutual attraction of the particles caused a *whirling motion* in the nebula, which gradually began to contract, get hotter and hotter, and finally assumed a globular shape. As the matter at the equator had a greater rotational velocity than at the poles, *rings* of matter became detached from the equatorial portion at the distance of each planet. These rings themselves afterwards condensed into globular form, revolving round the nebula and rotating on their axes in

the direction of the original nebula. Thus were formed the *planets*. If the planets were large enough, they might, in a similar manner, abandon rings, which would form *satellites*, revolving and rotating in the same direction as their primaries. In the meantime, the parent nebula went on contracting more and more, but becoming hotter and hotter. It finally remained as the *sun*, giving out light and heat to the bodies it had given birth to. The planets and the satellites, owing to their comparatively small size, must in the end cool by radiating their heat into space.

In the light of new laws and discoveries unknown in La Place's day, many modifications in the details of this theory have been proposed. With these modifications, most astronomers have accepted this grand theory, because it accounts for most of the leading features of the planetary system, enumerated in Art. 156, on mechanical principles. Besides, the testimony afforded by the existing nebulæ and stars, the earth itself and its moon, lends support, to a certain extent, to the view of the origin and growth of the solar system embodied in the Nebular Hypothesis.

If we accept this hypothesis of La Place, the same must, probably, have been the life-history of every *star* now seen; and the *nebulæ* existing now will go through a similar orderly evolution, bursting forth into new stars in ages to come. The existing stars will, in course of time, become dim and will finally be extinguished, having completed their cycle of evolution. We *have* such instances of *dark stars*; for example, the dark companion of Algol.

203. Lockyer's Meteoritic Hypothesis. Lockyer says that the original nebula was not a mass of glowing *gas* as La Place believed, but a swarm of *meteorites*, continually colliding with one another and giving rise to the faint light.

204. The Planetesimal Hypothesis. In the beginning of 1906, Professor Chamberlin, of the University of Chicago, formulated a new theory explaining the evolution of the Solar System.

PIERRE SIMON LA PLACE (1749-1827.)

He retains La Place's idea of a nebula having been the origin of the system, but says that the original nebula, instead of being a vast *gaseous* mass, was a great *spiral swarm* of *very cold solid separate particles*, each of which moved independently in its orbit like a planet. Hence he calls the theory the *Planetesimal Hypothesis*. These particles afterwards aggregated gradually into nuclei which formed the planets and the sun, and in the process of accumulation became intensely hot.

Professor Chamberlin claims that his theory not only satisfactorily accounts for the leading facts of the Solar System, but that it is free from the many serious objections to which the Laplacian theory is still open.

CHAPTER XVI.

DETERMINATION OF POSITIONS OF HEAVENLY BODIES AND OF PLACES ON THE EARTH.

205. Points and circles of reference. *The Celestial Sphere* is the imaginary hollow sphere, on the inside surface of which the heavenly bodies seem to be situated. If the axis of the earth be produced both ways, it will cut the celestial sphere in two points called the *North and South Celestial Poles*. (Fig. 84, P and P′.)

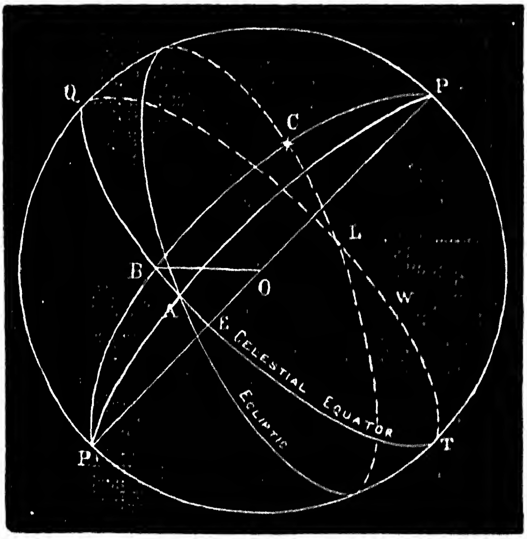


Fig. 84.—Illustrating Celestial Terms.

O, Observer.
PQP'T, Celestial Sphere.
PP'. Celestial Poles.
EQWT, Celestial Equator.
ACL, Ecliptic.
A, Equinox of Aries.
L, Equinox of Libra.
CB, Declination of Star C.
PC, Polar Distance „ „
Arc ATQB, Right Ascension of Star C.
PCBP', Star's Hour-Circle.

If the plane of the earth's equator be produced, it will intersect the celestial sphere in a circle, called the *Equinoctial or Celestial Equator.* It is 90° from the celestial poles. (Fig. 84, EQWT.)

The *Ecliptic* is the great circle on the celestial sphere which marks the apparent annual motion of the sun in the sky.(Fig. 84, ACL.) It is inclined to the equinoctial at an angle of $23\frac{1}{2}°$. The two points where they cut each other are called the "*Equinoxes.*" They are known as the "*Vernal Equinox*" or the *Equinox of Aries*" or the "*First Point of Aries*" (Fig. 84, A) and the "*Equinox of Libra*" or the "*Autumnal Equinox.*" (Fig. 84, L).

An *Hour-circle* is a great circle of the celestial sphere passing through the celestial poles (Fig. 84, PCBP′).

206. Co-ordinates of a star. The position of a point on a surface can be determined, if we know its distances from two fixed intersecting lines. These two distances are called the *co-ordinates* of the point.

The position of a star or any other heavenly body can be ascertained, if we know its co-ordinates. There are two principal systems of determining the co-ordinates of stars by means of circles and points, (1) the Equator System, and (2) the Horizon System.

In the *Equator System,* the celestial equator and the hour-circle of the vernal equinox or the First of Aries are the lines of reference,* and the co-ordinates are (1) *Declination or Polar Distance* and (2) *Right Ascension.*

The *Declination* of a star is its angular distance north or south of the equinoctial, measured along the hour-circle of the star (Fig. 84, CB). The *Polar Distance* of a star is its angular distance from either of the celestial poles, measured along its hour-circle. (Fig. 84, PC.). Hence Polar Distance $=90° -$ Declination.

* For this reason the vernal equinox is sometimes called the "*Greenwich of the Sky.*"

Declination may be north or south, according as the star is north or south of the equinoctial, and are distinguished by the signs + and — respectively.

The *Right Ascension* of a star is its distance from the hour-circle of the First Point of Aries, measured along the celestial equator always *eastward.* It is usually reckoned in *time,* from 0 right up to 24 hours ; but it may be counted also in degrees from 0° to 360°, since 360° are equivalent to 24 hours of the celestial rotation. (Fig. 84, arc ATQB). If a star is 30° east of the First of Aries, its right ascension is 2 hours or 30°. If a star is 45° west of this point, its right ascension is 21 hours or 315°. For right ascension, the abbreviation, R. A., is used.

In observatories the clock is not like the one we use. Its dial is divided into 24 hours, and it is so regulated that it indicates 0 hr. 0 min. 0 sec., when the First of Aries is on the meridian, so that the time the clock reads when any star is on the meridian is the R. A. of that star. The time shown by such a clock is called "*Sidereal Time.*"

The declination and right ascension of a heavenly body correspond to the latitude and longitude of a place, to be explained later on. Star-catalogues enable us to find the position of every star by giving us its declination and right ascension.

In the *Horizon System*, the fundamental line of reference is the horizon, and the co-ordinates of a star are its *Altitude* and *Azimuth.*

Altitude has already been defined in Art. 9. The *Azimuth* of a star is the arc of the horizon between the south point and the foot of the vertical circle of the star. It is usually reckoned from the south point right round through the west upto 360°. (Fig. 1, Arc SWNEH)

207. Importance of the determination of the positions of heavenly bodies. Astronomers have not only determined the positions of all stars, but can also calculate before-hand the positions of the sun, moon or any of the planets at any instant of time. The results of these calculations are given in the Nautical Almanac, which is published every year. This almanac is very useful to the traveller on land or the mariner on the wide ocean, as it enables him to find out exactly in what part of the world he is. The determination of longitude at sea is one of the most important

economic problems of astronomy, and the observatories at Greenwich and Paris were founded expressly for the purpose of supplying such astronomical observations as could be of use in accurately determining it. "Astronomy," says Todd, "binds earth and heaven in so close a bond that it even maps the one by means of the other, and guides fleet and caravan over wastes of sea and sand otherwise trackless and impossible."

DETERMINATION OF POSITIONS OF PLACES ON THE EARTH'S SURFACE.

208. Co-ordinates of a place on the earth's surface. The position of a place on the surface of the earth can be determined, if we know its co-ordinates, *viz.*, *latitude* and *longitude*. The two fixed lines used in finding these co-ordinates are the equator and some standard meridian.

209. Latitude of a place, and how to find it. The *latitude* of a place is its angular distance north or

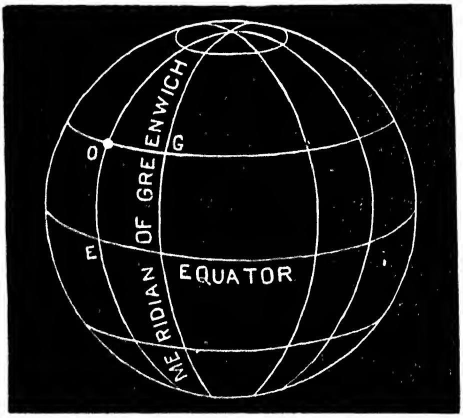


Fig. 85.—Latitude and Longitude of a Place.
OE, Latitude of the place O.
OG, Longitude " " " "

south of the equator. The equator is 0° latitude, and the north and south poles 90° N. and 90° S. latitude. (Fig. 85, OE.)

The latitude of a place north of the equator can be found out on land in two ways—(1) by applying the rule that "*the latitude of a place is equal to the mean altitude of the pole-star at that place*"; so that if we measure the mean altitude of the pole-star at a place with a meridian circle or a sextant or theodolite, that will give us also the latitude of the place. But this method cannot be applied in the southern hemisphere, where the pole-star is invisible.

(2.) The latitude can also be determined by measuring the zenith-distance of the sun or a star when on the meridian, if we know its declination. "*Latitude is equal to the declination* $\pm$ *zenith-distance, according as the body is south or north of the zenith.*"

At sea, the latitude is usually determined by observing the *sun's* meridian altitude, and finding out its declination from the Nautical Almanac.

The latitude of Bombay is 18° 53′ 45″ N.

Latitude of a place is equal to the altitude of the pole-star. This important theorem can be proved as follows:—

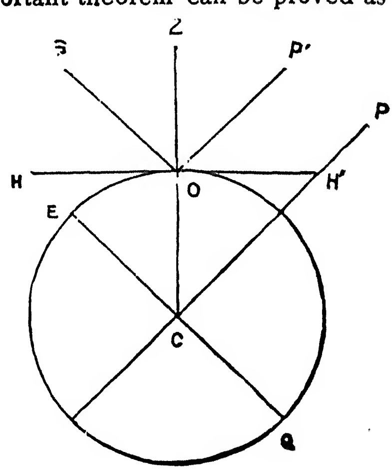


Fig. 86.—Latitude of a place is equal to the Altitude of the Pole-Star.

Let O, in Fig. 86, be the position of an observer on the earth, HH′ his horizon and Z his zenith. C is the centre of

the earth, EQ the equator, and P the celestial pole (or the pole-star). OP′ is parallel to CP, and therefore points in the direction of the pole-star. OS is parallel to EQ. The angle OCE is the latitude of the observer, and the angle H′OP′ the altitude of the pole-star.

Proof. Angle SOZ + angle ZOP′ = angle ZOP′ + angle H′OP′ = 90°.

Now angle OCE = angle SOZ = 90° — angle ZOP′ = angle H′OP′.

∴ *latitude of O = altitude of the pole-star.*

210. Longitude of a place, and how to determine it. *The longitude* of a place on the earth is its distance east or west from a particular meridian called the prime or first meridian. The meridian which passes through the transit instrument in the observatory of Greenwich is now almost universally regarded as the standard meridian. Longitude is generally measured, in *degrees*, by the arc of the equator intercepted between the standard meridian and the meridian of the place. (Fig. 85, OG) The meridian of Greenwich is longitude 0°. The greatest longitude of a place is 180° east or west. Longitude may also be measured in *hours*. As the earth rotates 360° in 24 hours, 15° of longitude correspond to one hour of time.

As the earth rotates from west to east, a place to the *east* of Greenwich will have its local* time *in advance* of Greenwich time, and every place *west* of Greenwich has its time *behind* Greenwich time, since the local time is regulated by the sun, which rises earlier at the place east of Greenwich, and later at the one west of it.

To determine the longitude of a place, we must know its local time and the Greenwich time at a particular instant. For example, suppose the local time to be 3. P. M., when the

* The mean solar time of a place is called its *local time* (Cf. Art. 225.)

Greenwhich time is 12 noon. The local time being 3 hours *in advance* of Greenwich time, the longitude of the place is 3 hours or $3 \times 15^\circ = 45^\circ$ east. The local time can be found out easily by observing the position of the sun by a transit-instrument or a sextant. The Greenwich time can be known by the telegraph, if we are on land.

On sea, where the determination of longitude is of the greatest importance, the telegraphic method cannot be employed. The captain, however, ascertains the Greenwich time by accurate chronometers keeping Greenwich time which are carried by every ship.

Several such chronometers are kept on board a ship, to check each other, and they are all 'rated' in port, *i. e.*, their error and their daily gain or loss are determined by comparisons for several days with an accurate clock kept correct to Greenwich time. But during a voyage they may show different times. They can, however, be checked by observing certain astronomical phenomena, such as the eclipses of Jupiter's satellites, occultations of stars by the moon, etc. These phenomena are predicted and published in the Nautical Almanac every year, and can be observed simultaneously at many places on the earth. If we compare the time of their actual occurrence according to the chronometer with that given in the almanac, the error of the instrument can be found out.

The longitude of Bombay is $72^\circ 52'$ E.

211. Standard Time. We have seen in the earlier chapters that, as the earth is spherical, all places on it having the same longitude have the same local time, but places having different longitudes have different local times. Formerly, as each place kept its own local time, in travelling even a small distance east or west, one had to change his watch to the local time of the place visited. Before the days of the railway, this was perhaps not very annoying. Even after the introduction of railways, as each railway ran its trains by the time of its own meridian, the traveller was often liable to miss his train by not knowing the relation between his watch and the railway time. But, besides this inconvenience, if every place along a railway extending east and west

were to keep its own local time, there would be great confusion and considerable danger in running trains. To avoid this, the present system of *standard time* was introduced, under which standard meridians are adopted 15° apart. Places situated in a zone extending 7° or 8° on each side of a standard meridian use the local time of that meridian. This time is called the *standard time*. The longitudes which mark the zones are reckoned east or west from Greenwich.

At present, standard time is in use in every civilized country in the world. The British Islands, Belgium and Holland use as standard time the local time of the meridian passing through the Royal Observatory at Greenwich. In France, the standard time used is the local time of the meridian passsing through the Paris Observatory. Germany, Italy, Switzerland and Sweden use the local time of the meridian one hour east of Greenwich. In Japan and South Australia, the standard time is the time of the meridian 9 hours east of Greenwich.

Canada and the United States of America are of so great an extent in longitude that it was found inconvenient to adopt *one* standard time. It was, therefore, necessary to divide these countries into 4 zones 15° of longitude in width and to use 4 hours of standard time, called respectively Eastern Time, Central Time, Mountain Time and Pacific Time, which are 5, 6, 7, and 8 hours respectively slow on Greenwich.

Indian Standard Time. In India, upto 1904, each place kept its own local time, but the railway time was the local time of the meridian passing through Madras, and was shortly called *Madras Time*, which is 5 hours 22 minutes faster than Greenwich time. Travellers, whose watches were regulated by their own local time, were, consequently, subjected to great annoyance; so, in 1905, the Indian Government, following the example of other leading countries, adopted, all throughout India, one *standard time*, which is $5\frac{1}{2}$ hours faster than Greenwich time, and is to be used for regulating railroad traffic and all ordinary affairs. Its introduction has facilitated

all railway and telegraph business, and has made it easy for every one to keep accurate time, which is distributed every day by Madras.

The Indian Standard Time is about 39 minutes faster than Bombay local time, and about 21 minutes slower than the local time of Calcutta. The local time of Bombay is about 4 hours 51 minutes fast on Greenwich.

It may be noted that, with two or three exceptions, the standard meridians adopted throughout the world are an *integral* number of hours from the prime meridian of Greenwich.

212. Problems.

1. *An eclipse of one of Jupiter's satellites was observed by the captain of a ship at 9-45 P. M. (local time), when his chronometer, keeping Greenwich time, indicated 4 P. M. Find the longitude of the ship.*

The difference between local and Greenwich time is 5 hours 45 minutes. Now for one-hour difference in time, there is a difference of 15° between the longitudes. Hence

$$1 \text{ hr.} : 5\tfrac{3}{4} \text{ hrs.} :: 15^\circ : x^\circ$$

$$\therefore x = 86\tfrac{1}{4}^\circ = 86^\circ\ 15' = \text{Longitude required.}$$

Since the local time is in *advance* of Greenwich time, the longitude is $86^\circ\ 15'$ *East*. $86^\circ\ 15'$ E. *Ans.*

2. *The longitude of a place is 75° West. If the Greenwich time is 2-35 P.M., what is the local time?*

$$15^\circ : 75^\circ :: 1 \text{ hr.} : x \text{ hrs.}$$

$$\therefore x = 5 \text{ hrs.}$$

The difference between Greenwich and local time is, therefore, 5 hrs. But as the longitude of the place is West, its local time must be 5 hours *behind* Greenwich time. Now the Greenwich time is 2-35 P.M., therefore the local time is 9-35 A.M. 9-35 A.M. *Ans.*

3. *The longitudes of two places A and B are respectively 80° E. and 50° E., the local time of A is 4-30 P.M.: what is the local time of B at the same instant?*

As both the longitudes are E., the distance between the places is $80^\circ - 50^\circ = 30^\circ$, and the difference between their

local times must be $(30 \div 15)$ hrs. $=2$ hours. But since B is *west* of A, (being nearer Greenwich than A) the local time of B is 2 hours behind that of A, *i.e.*, the local time of B is 2-30 P.M.

2-30 P.M. *Ans.*

4. *The local time of a place P, (long. 70° W.) is 12 noon: find the local time of another place, Q, (long. 100° E.)*

The distance between the two places is $70^\circ + 100^\circ = 170^\circ$; therefore, the difference between their local times is $(170 \div 15)$ hours $= 11$ hrs. 20 min. Since Q is east of P, the local time of Q must be faster than that of P. Hence the local time of Q is 11-20 P.M.

11-20 P.M. *Ans.*

5. *A ship is in Lat. 36° 45′ North, and Long. 25° W. Find the latitude and longitude of the point on the earth farthest from the ship.*

The point farthest from the ship must be one exactly opposite on the earth. Hence its latitude must be 36° 45′ South, and it must be 180° east or west from the ship. But the longitude of the ship itself being 25° W., the longitude of the point must be $180^\circ - 25^\circ = 155^\circ$ East.

Lat. 36° 45′ South; Long. 155° E. *Ans.*

6. *A mariner observes the pole-star to be 30° above the horizon. The next day, when the sun is at its greatest altitude, his chronometer, keeping Greenwich time, shows 3-30 P.M. Find his latitude and longitude, supposing his ship does not move in the interval.*

The pole-star is visible only in the northern hemisphere; and as the altitude of the pole-star is = the latitude of the place, the *latitude* of the sailor is 30° N.

When the sun is at its greatest altitude, the local time is 12 noon. But the Greenwich time, according to his chronometer, is 3-30 P.M.; therefore the difference between the two times is 3 hours 30 minutes. Hence the longitude of the ship is $3\frac{1}{2} \times 15^\circ = 52\frac{1}{2}^\circ$; and, as the local time is *behind* Greenwich time, the longitude is West.

Lat. 30° N.; Long. $52\frac{1}{2}^\circ$ West. *Ans.*

7. *The declination of a star was found to be* 12° *N., and its zenith-distance was* 10° *S. What is the latitude of the place?*

As the star is 10° *south* of the zenith, the latitude=declination + zenith-distance (Art. 209), *i. e.*, latitude$=12^\circ+10^\circ=22^\circ$ N.

8. *A star, having Dec.*$+41^\circ$, *was observed* 25° *north of the zenith. Find the latitude of the place.*

As the star was 25° *north* of the zenith, the latitude= declination — zenith-distance. (Art. 209.)

$\therefore$ lat. $=41^\circ-25^\circ=16^\circ$ N. 16° N. *Ans.*

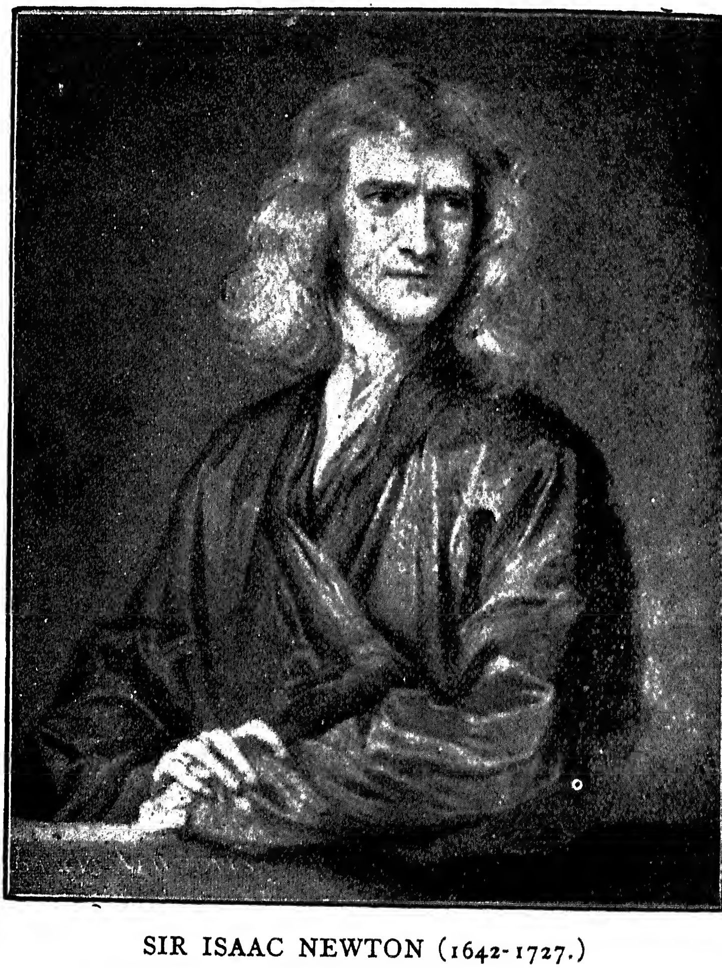
9. *The zenith-distance of a star, having Dec.*-24°, *is* 14° *S. What is the latitude?*

The star being *south* of the zenith, latitude = declination + zenith-distance.

$\therefore$ lat. $=-24^\circ+14^\circ=-10^\circ$.

The negative sign shows that the latitude is *south*.

10° S. *Ans.*



SIR ISAAC NEWTON (1642-1727.)

CHAPTER XVII.

GRAVITATION.

213. Newton's Law of Gravitation. When Kepler discovered his famous three laws of planetary motion, he could give no reason for them, on account of the backward state of the mathematical and mechanical sciences in his time. It was reserved for the brilliant genius of Sir Isaac Newton to read their hidden meaning. In 1687—fifty-seven years after Kepler's death—Newton, by his reasoning and mathematical calculations based on these laws, deduced the following three inferences from them, which he summed up in his celebrated "*Law of Gravitation*":—

1. (From the second law.) The force which keeps the planets in their orbits is an *attractive force directed towards the sun.*

2. (From the first law.) The attractive force on any planet at different points in its orbit *varies inversely as the square of the planet's distance from the sun.*

3. (From the third law.) The attractive force on *different* planets *varies directly as the product of their masses and inversely as the squares of their distances* from the sun.*

Newton further showed that this attractive force, which he named '*gravitation*,' is the very same that, pulling terrestrial bodies, makes them fall towards the earth and gives them the property of weight (*gravitas*), as well as extends outwards from the earth's surface as *far as the moon and holds it in its orbit.* He said that even the distant stars were controlled and guided in their courses by the force of gravitation. In fact, he demon-

* The third inference shows that the attractive force depends only on the masses and distances of the bodies concerned, and is quite *independent of their physical condition*, *i. e.*, whether they are hot or cold, wet or dry, solid, liquid or gaseous is of no account in determining the force.

strated that the force resides *in every particle of matter in the universe*; hence its name *universal gravitation*. As Comstock says, "To Kepler and his age the heavens were supernatural, while to Newton and his successors they are a part of Nature, governed by the same laws which obtain upon the earth."

The *Law of Gravitation* is enunciated thus :—

"*Every particle of matter in the universe attracts every other particle with a force which varies directly as the product of the masses and inversely as the square of the distance between them.*"

Though Kepler's laws formed the basis upon which Newton built his law of gravitation, once the general law was established, it was clear that Kepler's laws were the necessary consequences following from it.

Gravitation varies as the product of the masses. If the masses of two bodies at a certain distance from each other be 1 and 2, and if the attraction between them be called unity, then, if the masses of the bodies become 2 and 3 (the distance remaining the same), the new attraction will be $2 \times 3 = 6$ times the old attraction, or six units.

Gravitation varies inversely as the square of the distance. Suppose the attraction between two bodies at a certain distance from each other is one unit. Then if the distance be *doubled*, but their masses remain the same, the pull between them is not half, but $(\frac{1}{2})^2 = \frac{1}{4}$ the original pull. If the distance is *trebled*, the new attraction between them is $(\frac{1}{3})^2 = \frac{1}{9}$ the old attraction.

If m, m' represent the masses of two particles, d the distance between them, and A the attraction between them, then A varies as $\frac{m.m'}{d^2}$

214. Importance of the Law of Gravitation. "In all the domain of physical science," says Comstock, "there is no law so famous as the Newtonian law of gravitation; none other that has been so dwelt upon, studied and elaborated by astronomers and mathematicians, and perhaps none that can be considered so indisputably proved." Every body in the universe obeys the law, whether it be a leaden ball, a moon, a planet or a distant star. The plan-

ets revolve round the sun, and the satellites round their primaries in obedience to this law. The motions of the heavenly bodies appeared before Newton's time very irregular and incapable of any satisfactory explanation. But Newton proved that all these movements, however complicated, were really regular and controlled by one single law, the Law of Universal Gravitation. Many astronomical phenomena, such as the tides, the perturbations of planets, the precession of the equinoxes and others, which baffled explanation, can be completely accounted for on the theory of gravitation, nay, even their occurrence as well as their consequences can be correctly *predicted*. Newton thus enabled us "to admire the beauty and harmony of the universe in which we dwell." Pope truly says—

> Nature and Nature's laws lay hid in night:
> God said, 'Let Newton be,' and all was light.

215. Why the moon revolves round the earth. The earth and the moon attract each other, but as the earth is much larger than the moon, it attracts the moon with a greater force than that which the moon exerts on the earth. The consequence should be that the moon must fall on the earth. But it does not. Why? Because, before the earth first began to pull the moon, the latter had, in some way or another, been set into motion in a straight line away from the earth. This tendency to move in a straight line the moon still retains, according to Newton's "First Law of Motion," while it is pulled by the earth. The moon is, therefore, acted upon, at any point in its orbit, by two forces,—the centrifugal force originally impressed upon it, and the earth's attraction which tends to make it fall towards it. The consequence is that the moon follows the direction of the resultant of these forces, and moves in a *curvilinear* orbit round the earth. Were it not for the restraining influence of the earth, the moon would fly off far away from it.

The *planets* move round the sun for a similar reason. The original impulse received by them, combined with the

attractive force constantly exerted on them by the sun, keeps them revolving round the sun in an elliptical orbit.

The force with which the earth attracts bodies on its surface as well as the moon is called '*Gravity*.' Newton showed that it is only a *special case* of the much more general fact of the *Law of Gravitation*.

216. How Newton tested the law of gravitation by the motion of the moon round the earth. Newton tested that attraction varies inversely as the square of the distance by the following method.

The force of gravity on the earth is measured by the distance through which a body falls under its influence in one second. A body at the *surface* of the earth, *i. e.*, 4,000 miles from its centre, falls 16 feet in one second, if let fall freely. Now the moon is about 240,000 miles from the centre of the earth, *i. e.*, 60 times $\left(\frac{240,000}{4,000}\right)$ farther from the centre of the earth than a body on its surface. Hence, if gravitation varies inversely as the square of the distance, the moon ought to fall towards the earth $\frac{1}{60^2} \times 16$ ft. $= \frac{16}{3600}$ ft., in one second. Newton showed that it *was* so as follows:—

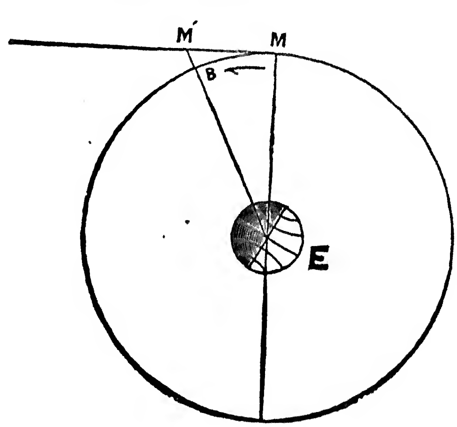


Fig. 87.—Fall of the Moon towards the Earth.

If gravity ceased to act, the moon would move in a *straight* line. In Fig. 87, suppose in one second it moves thus through

the distance MM′. But if gravity also acts upon it, the earth will bend its path and make it fall, say, from M′ to B in one second. Now, knowing the size of the moon's orbit and its periodic time, Newton calculated that M′B was just $\frac{16}{3600}$ ft. Thus he showed that when the distance was 4,000 miles, the space fallen through was 16 ft.; when the distance was 60 times greater, the space through which the moon fell was $\frac{1}{60^2}\times 16$ ft., that is, he verified by means of the moon's motion that *gravitation varies inversely as the square of the distance.*

217. Perturbations. As gravitation is true of all bodies, planets also attract one another and cause mutual disturbances in their elliptical orbits. Such disturbances are called "*Perturbations.*" Their computations require the highest mathematical skill. It was the perturbation, long observed in Uranus's orbit, but not fully accounted for, that suggested, as we have seen in Art. 150, the possibility of an unknown body outside the orbit of that planet and led to the discovery of Neptune.

The *masses* of planets can be determined by means of the perturbations they produce in the motions of their satellites (if they have any), or in those of other planets, or of comets that come near them.

La Place and Lagrange showed near the end of the 18th century that the mutual attractions of the planets would not cause such serious changes in their orbits as to affect the stability of the Solar System.

218. Tides. Those of us who live near the sea-shore can find, even after a week's careful observation, that there is a regular rising and falling of the waters of the ocean at intervals of 12 hours 25 minutes. For 6 hours 12 minutes the sea gradually rises, then falls slowly during the same period—to rise and fall again during the next 12 hours 25 minutes. This alternate rise and fall of the ocean is called *tides*. It is *flood*-tide while the water is rising; when it is falling it is *ebb*-tide. When the water-level is highest, it is called *high-water*, and when it is lowest, it is said to be *low-water.*

We have seen in Chapter VII that the moon rises, culminates and sets on an average about 51 minutes later every day. Thus the average interval between the successive passages of the moon across the meridian of a place is 24 hours 51 minutes. This period is called the *mean lunar day.* The average interval between corresponding high waters on successive days is also 24 hours 51 minutes. This coincidence, which was early noticed in human history, must have made it certain that a close connection existed between the tides and the motion and position of the moon. But the true nature of the influence of the moon in causing this phenomenon was first determined by Newton, who *worked out the theory of tides on his law of gravitation.* He proved that the tides were produced mainly by the *attraction* of the moon, and in a much lesser degree by the attraction of the sun, on the water of the earth.

The moon's influence in causing tides. Suppose the earth is uniformly covered with water. As attraction varies inversely as the square of the distance, the effect of the moon's

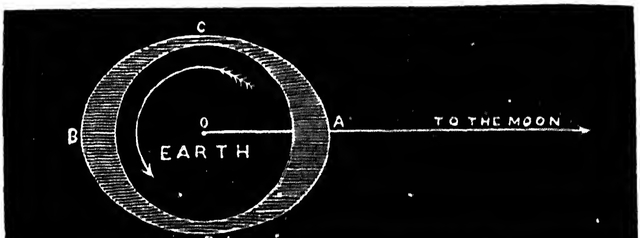


Fig. 88.—The Tides.

attraction on A (Fig. 88)—the side of the earth nearest to it—will be greater than that on C, the earth's centre, and, since water moves more freely than solid land, it will be drawn away from C and D, which are 90° from A, and heaped up at A, causing high water. This is called *the direct tide.*

Similarly, the centre of the earth being nearer the moon than the water at B on the further side, the solid earth is pulled by the moon with a greater force than this water is, and drawn away, as it were, from the water at B. The effect is that the

water at B is left bulged out in precisely the same way as the water on the side under the moon. Hence there is another high tide at the same time on the side of the earth away from the moon. It is called *the opposite tide.*

At C and D, 90° from A or B, there are low tides, the result being that the water of the globe assumes an ellipsoidal (lemon-shaped) form, with its long diameter pointing to the moon. (Fig. 88.) Thus Newton showed that the cause of the tides is the *differential attraction of the moon (and the sun)* upon the solid earth and the water nearest and farthest from them.

If the moon attracted the centre and the surface of the earth with an equal force, the solid earth and the water would be pulled as if they were one body, there would be no heaping up of the water anywhere, and, consequently, there would be no tides.

If the earth did not rotate, the tidal wave would travel from west to east round our globe with the moon, and high water would occur at places exactly under the moon and at those 180° from it, but then we should not have *two* tides a day. It is the earth's rotation which brings every place under and away from the moon daily, and causes each place on the sea-shore or the ocean to have two tides every day. As the moon, however, comes on the meridian about 51 minutes later every day, the average interval between high or low waters is 24 hours 51 minutes. Since, also, the earth turns eastward on its axis, the watery bulge seems to travel from east to west.

The sun's tide-producing force. The sun also acts on the earth precisely as the moon does, but the sun being about 390 times farther from the earth than the moon, its tide-producing force,* notwithstanding its vastly greater mass, is only $\frac{2}{5}$ that of the moon.

* Newton proved that the tide-raising force of a body varies directly as its mass, and inversely as the *cube* of its distance. As the sun's mass is 26,500,000 (81×332000) times that of the moon, the sun's tidal action is $\frac{26,500,000}{(390)^3}$, or about $\frac{2}{5}$, that of the moon.

Spring and Neap Tides. Near the times of new moon, and full moon, the sun being in a line with the moon and the earth, the tidal effect of the sun is added to that of the moon, so they *combine* in producing every fortnight higher tides than usual. These are called *spring tides.* (Fig. 89.)

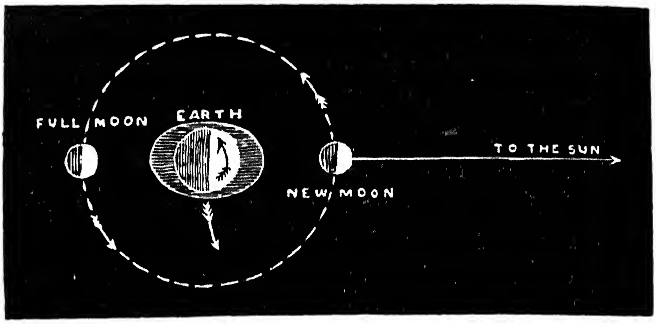


Fig. 89—Spring Tides.

When, however, the moon is in its quarters, as in Fig. 90, the sun's influence is exerted at right angles to, and athwart, that of the moon. Consequently, the tides that happen at such a time are lower than usual, and are called *neap tides.*

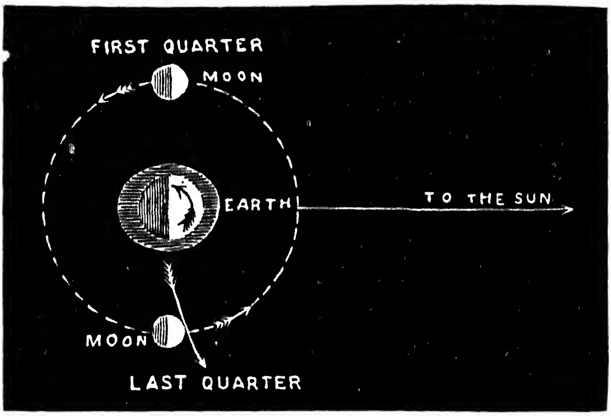


Fig. 90—Neap Tides.

Thus in a lunar month, besides the daily tides there will be two largest and two smallest tides, separated by a fortnight.

Since the moon's tidal effect is to that of the sun as 5:2, the height of the average spring tide is to that of the neap tide is as (5+2) : (5—2), *i. e.*, as 7:3.

When the moon is in perigee, the tides are 20 per cent. higher than when it is in apogee. For the same reason the tides in winter are higher than in summer, because the earth is then nearer to the sun. The *highest tides of all* happen when the moon is in perigee at the new or full moon which occurs about 1st January, when the earth is nearest to the sun.

Priming and lagging. Between new moon and first quarter, and between full moon and last quarter, the interval between two successive high waters is less than the average, being about 24 hrs. 38 min. (instead of 24 hrs. 51 min.) In such cases, high water occurs a little *before* its usual time, and the tides are said to '*prime.*' In like manner, between first quarter and full moon and between last quarter and new moon, high water will occur a little *later* than usual—about 25 hrs. 6 min., and the tides are said to '*lag.*'

On account of the barriers offered to the passage of the tidal waves by continents, lunar high tide does not occur when the moon crosses the meridian; it occurs later than it would on theory, by an interval which is constant for a given place. The mean interval between the time of high water at a port and the preceding passage of the moon across its meridian is called the *establishment of the port.* It is different for different places, owing to the irregular distribution of land.

The difference of level between high and low water is called the *range of the tide.* It varies in different places, and depends chiefly on the shape of the land.

Tidal friction, and its effects. In the case of tides occurring in mid-ocean, the motion of the water consists

merely in the rising and falling of its particles. But near the land this oscillatory motion is changed into a bodily movement, as the water rolls to and from the shores. This causes a great deal of fluid friction, called *tidal friction,* which must involve the loss of an enormous amount of tidal energy. Where are these vast stores of energy abstracted from? It is suggested that it must be derived from the energy of rotation of the earth. As the earth steadily moves on through its liquid envelope, this *tidal friction acts as a break,* and the effect is that the earth's *rotational velocity* is *lessened* and the *day lengthened.* But owing to certain counteracting causes, this loss of energy and the consequent diminution of the speed of rotation must have been extremely minute; in fact, there is no conclusive evidence that the day has become longer by even $\frac{1}{6}$th of a second during the last 2,500 years.

One other tendency of tidal friction is to make the *moon recede from the earth* and thus to *lengthen the month.* From this it is inferred that the moon was formerly much nearer the earth than at present.

CHAPTER XVIII.

MISCELLANEOUS.

219. **How the diameter of the earth is determined.** The following will give an idea of the principles of the method by which the earth's diameter can be determined. We shall assume that the earth is a perfect sphere.

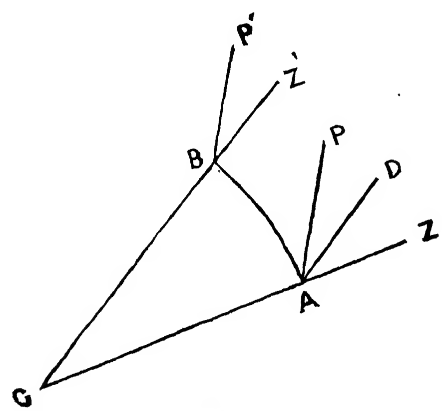


Fig. 91.—How the Diameter of the Earth is found.

In Fig. 91, C is the centre of the earth, and A and B are two places on the same meridian. AP and BP′ both point to the north celestial pole, and AZ and BZ′ are drawn in the direction of the zenith of the two places. Draw AD parallel to BZ′.

Then ∵ CZ′ is parallel to AD

∴ angle ACB = angle D A Z

= angle PAZ — angle P A D

= angle PAZ — angle P′BZ′ (∵ A P is parallel to BP′)

An astronomer at A measures the angle PAZ, then he travels northward to B, carefully measuring the length of A B

by a system of indirect measurement called the "triangulation method."* At B he measures the angle P′BZ′.

Thus he now gets the value of the angle ACB, subtended by the arc AB. If ACB be 1°, the arc AB is also 1°. Therefore, he knows that an arc of 1° = measured length of AB in miles. Hence the *circumference of the meridian, i.e., of the earth* will be 360 × length of AB in miles. The *diameter* of the earth is obtained by dividing the circumference by 3.1416.

Many arcs of meridian have been measured in this way, and the average length of a degree of meridian has been found to be about 69.1 miles. Hence the mean circumference is 360×69.1 miles = about 25,000 miles, and the mean diameter is about 7,917 miles.

The true shape of the earth. If the earth were a perfect sphere, a degree of meridian either at the equator or at the pole should be of the same length; but accurate measurements at different latitudes indicate that a degree of meridian is invariably longer, the nearer the pole is approached. It has been found that the arc of 1° at the equator =68.7 miles, but it increases gradually, till, at the north pole, the arc of 1° = 69.4 miles. This clearly shows that the curvature of meridians decreases towards the pole, because the less the curvature of a circle, the longer the degrees on it; in other words, *the earth is flattened at the poles*. It is, therefore, not perfectly spherical, but a *spheroid*, having its polar diameter shorter than the equatorial diameter by about 26 miles (*Cf.* Art. 10); hence it is an *oblate spheroid*. But even the equator has been found by recent measurements to be not a true circle. The *true shape of the earth* may, therefore, be said to be an *ellipsoid*, with three unequal diameters or axes.

* It is the process of finding the exact distance between two remote points by a network of *triangles*.

That branch of mathematics which determines the exact magnitude and shape of the earth or of any large portion of its surface is called *Geodesy*. Most of the civilized governments have conducted accurate geodetic surveys of their territories by the triangulation method.

220. Twilight. Twilight is the faint and diffuse light perceived long before sunrise and after sunset. The twilight in the evening is known as *dusk*, while that which precedes sunrise is called *dawn*.

Cause. In our atmosphere there are minute particles of dust and vesicles of water. After the sun has set, its rays still pass through the higher regions overhead of the atmosphere, and light up these particles. These illuminated particles reflect the light down to the surface of the earth, and produce twilight. But as the sun sinks more and more below the horizon, the intensity of this light diminishes, and when the sun gets about 18° below the horizon, twilight altogether ceases. (Fig. 92). It is said to end when stars of the sixth magnitude become visible near the zenith.

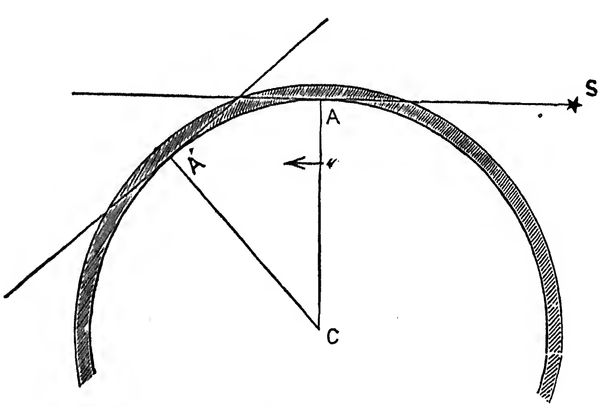


Fig. 92.—Duration of Twilight.
When the place A has turned through the angle ACA' (18°), twilight ceases.

If the earth had no atmosphere, the moment the sun set, there would be total darkness on the earth. So also there

would be no light at all before the sun actually rose above the horizon.

The *duration of twilight* varies at different seasons as well as at different latitudes. The higher the latitude, the longer the twilight; so that in the tropics twilight is very short, being less than half-an-hour at some places. But at the poles it is about 2½ *months* in duration. This mitigates to a great extent the otherwise intense darkness of the six months' night at the poles.

221. Atmospheric Refraction. Our atmosphere, the height of which is supposed to be about 100 miles, consists of a number of layers of different densities, the highest being the least dense and the lowest the most dense. Now a ray of light, passing from one medium to another of a different density, is bent out of its course, unless it strikes the surface of the denser medium perpendicularly. This bending is called *refraction*. When the rays of light from a heavenly body, passing through the earth's atmosphere, are deflected from their straight path, the phenomenon is called *atmospheric refraction*.

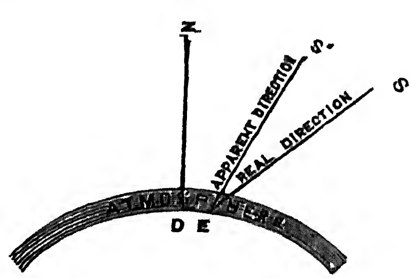


Fig. 93.—Atmospheric Refraction.

In Fig. 93, a ray coming from a star S has to pass through layers of air of various densities, so it is continually bent out of its course, till when it reaches the eye E, it comes in the direction SE. Now since the star is seen in the direction from which the ray enters the eye, it appears to be situated at S′, not at S. But S′ is nearer to the zenith Z than S, hence the effect of refraction is to make heavenly bodies appear

higher than they really are. When a body is at the zenith, the rays fall perpendicularly on the atmosphere, so there is no refraction. At the horizon, it reaches the maximum.

Astronomical effects of refraction.

(1) Refraction raises the sun and the moon, when rising or setting, more than half a degree, so that, even when they are really below the horizon, we can see them. The result is that the length of the day is longer than calculations show, because sunrise is accelerated and sunset is retarded.

(2) Another effect of refraction is to slightly distort the image of the sun when near the horizon. The nearer a body is to the horizon, the greater the refraction. By refraction the lower edge, which is nearer to the horizon, is raised more than the upper, so the sun's disc assumes the form of an ellipse flattened on the underside, with its major axis parallel to the horizon.

(3) On account of refraction, during a total lunar eclipse, the moon is never perfectly dark, but shines with a copper-coloured light, as we saw in Art. 56.

222. Precession of the equinoxes. We have seen (Art. 26) that the earth's axis in its journey round the sun always remains parallel to itself, *i. e.*, points to the same star—the pole-star. But this is not strictly true. The axis has a slow conical motion, so that its north pole revolves in a small circle once in about 25,800 years, just as the axis of a top traces out a cone when its motion slows down. If the axis of the earth shifts its position, the celestial poles and consequently the equinoctial must likewise move. Now the equinoctial cuts the ecliptic in two points, called the equinoxes. The consequence is that the equinoxes themselves also slowly *shift westward* on the ecliptic. This slow motion of the equinoxes from east to west along the ecliptic is called the "*Precession of the Equinoxes,*" first discovered by Hipparchus about 125 B.C.

The amount of precession yearly is $50''.2$, so that the equinoxes make a complete circuit of the ecliptic in 25,800 years ($360° \div 50.''2$). As the sun moves along the ecliptic from west

to east, it meets every year the equinoxes twenty minutes earlier than the preceding year.

The cause of the conical motion of the earth's axis was first explained by Newton. He showed that it was due to the action of the sun and the moon on the protuberant ring of matter round the equator of the earth, tending to make the plane of the equator coincide with the plane of the ecliptic.

Effects of the precession.

(1) On account of this shift of the earth's axis, the north celestial pole also describes a small circle round the pole of the ecliptic in 25,800 years, and so comes in different constellations, as centuries roll by. Now the pole is about $1\frac{1}{4}°$ from the pole-star, but about 2,000 years ago, the distance was $12°$, and 100 years hence it will be only $\frac{1}{2}°$. In other words, the pole-star in the past was not the same as it is now, nor will it remain the same in future.

(2) The *signs* of the Zodiac no longer correspond with the *constellations* after which they were named. Once the *sign* of Aries coincided with the *constellation* of Aries. It is not so now; it is now in the constellation of Pisces. Each sign has backed into the constellation west of it in the last 2,000 years.

(3) Owing to the shifting of the equinoctial, the declinations and right ascensions of stars also constantly change.

(4) As the sun meets the Equinox of Aries 20 minutes earlier every year on account of the precession, our tropical year becomes 20 minutes shorter than it would be otherwise. (*Cf.* Art. 226.)

223. Parallax. *Parallax,* in its wide sense, is the difference in the direction of a heavenly body as seen from two different standpoints; it is the angle formed by two lines drawn from the object to the two standpoints. Usually, however, *parallax* is the angle between the two lines joining the body to the *observer* and the *centre of the earth*; in other words, it is the angle subtended at the object by the *radius of the earth.* (Fig. 94, Angle NMO). The standard radius adopted

is the equatorial radius. When the body is on the horizon the parallax is the greatest, and is called the *horizontal parallax*; at the zenith it is *nil*. The parallax of a body diminishes as the distance increases. It is, consequently, very difficult to measure the *parallax of stars*. It is not so with regard to the sun, moon and the planets, which are comparatively nearer to us. In the case of a star, therefore, the parallax measured is the angle subtended at the star by the sun's mean distance from the earth, *i. e.*, by the *radius of the earth's orbit*. This parallax is called *heliocentric parallax*

224. Distance of a heavenly body deduced from parallax.—When the parallax of a heavenly body is known, its distance can be easily calculated by trigonometry. The determination of parallax is, therefore, a very important problem in astronomy. The parallax usually found is *the horizontal equatorial parallax*.

Determination of the moon's distance. To calculate the distance of the moon from the earth, its parallax must first be determined. This is done on the same principle as that on which surveyors find the distance of an inaccessible object (by the "triangulation method.") Two places situated as nearly as possible on the same meridian, but far apart from each other, (for example, Greenwich and Cape Town,) are

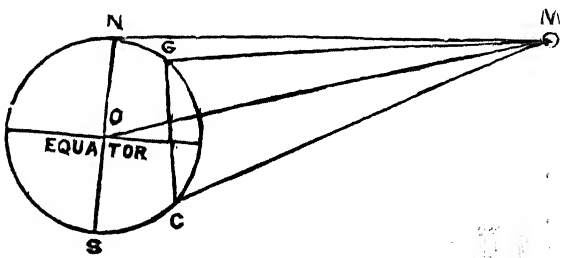


Fig. 94.—Determination of the Moon's parallax.

selected, and the distance between them is accurately found (Fig. 94.) This forms the 'base-line' GC. Then the angles

CGM and GCM between the ends of the base-line and the directions in which the moon is observed are measured by delicate instruments at both places. Knowing the two angles and one side of the triangle GMC thus formed, we can solve the triangle by trignometry and thus determine the moon's distance from Greenwich or the Cape. Then, by further calculations, the angle NMO, which is the parallax of the moon, can be found; and thence, the distance, O M, of the moon from the centre of the earth.

The equatorial horizontal parallax of the moon is 57′ 2″, hence its mean distance from the earth is 238,840 miles.

The mean angular diameter of the moon is 31′ 7″. Knowing this and its mean distance from the earth, we can easily compute *its real diameter* in miles, which is found to be 2,163 miles.

Determination of the sun's distance. This is a problem of vast importance and difficulty, on which astronomers have spent a great amount of energy. If we know accurately the parallax of the sun, the determination of its distance follows easily. The solar parallax is found by various methods, of which the following are the more prominent :—

1. By measuring the parallax of Mars or one of the nearer asteroids at its opposition, and thence determining the distance of that body in miles. As we can compute also its distance from the earth in astronomical units, the value of that unit can be determined *in miles*. For this purpose, the recently discovered asteroid, Eros, promises to be much utilized.

2. By observations on the transits of Venus. This method was first suggested by Halley in 1677.

3. By knowing the velocity of light and the time taken by light to travel between the sun and the earth. This time (which is called "*the constant of light equation*") can be determined by observations on the eclipses of Jupiter's satellites. By simply multiplying this time (499 seconds) by the velocity of light (186,330 miles per second), we get at once 92,979,000 miles for the sun's distanee.

4. By the perturbations produced by the earth on the orbits of Venus and Mars. Young says, "This method is probably the method of the future and in time will supersede all the others."

Even a very elementary explanation of the principles involved in all these methods is beyond the scope of this little work. The results obtained by the different methods, however, closely agree.

The most recently determined parallax of the sun is 8″.80, and consequently its distance from the earth is about 92,900,000 miles.

225. Sidereal Day and Solar Day. The interval between two successive transits of any *star* across the meridian of a place is called the "*Sidereal Day.*" It is invariable, and consists of 23 hours 56 minutes and 4 seconds. As the daily movement of the star is due to the rotation of the earth, this day is also the exact period of the eatth's rotation. The sidereal day begins when the First Point of Aries comes on the meridian. As the transit may occur at any time during the day or during the night, the sidereal day is an inconvenient unit of time for practical purposes. But every astronomical observatory has a clock which keeps the *sidereal time.* The hours are numbered from 0 to 24.

The interval between two successive transits of the *sun* over the meridian of a place is called the "the *Apparent* or *True Solar Day.*" But owing to (1) the variable eastward movement of the sun in the ecliptic, due to the eccentricity of the earth's orbit and (2) the obliquity of the ecliptic, the true solar day *varies* throughout the year from 23 hours 44 minutes to 24 hours 14 minutes. It is indicated by a sun-dial.

For our ordinary affairs of life, such a variable day would be an inconvenient standard, so the average of the lengths of all the solar days in the year is taken. This mean length is called the "*Mean Solar Day.*" It is divided into 24 mean solar hours, the hours into 60 solar minutes, and the minutes into 60 solar seconds. Our ordinary clocks keep this *mean solar time.* (The mean solar time of a place is called its *local time.*) The solar day is thus 4 minutes longer than the sidereal day. It is reckoned from *mean noon to mean noon* through 24 hours. As this is the day also recognized by astronomers and navigators, it is otherwise called the "*Astronomical Day*"

The ordinary or *Civil Day* also consists of 24 hours, but it is divided into two periods of 12 hours each, and is reckoned from the *midnight* preceding the noon of an astronomical day to the next following *midnight*. The hours of its first period are called A. M. (*Ante Meridiem*, that is, before midday), and those of the second are called P. M. (*Post Meridiem*, that is, after midday).

The difference between mean solar time and apparent solar time on any day is called the "*Equation of Time.*" It is the number of minutes which must be added to, or subtracted from, the apparent time to get mean time. On four days in the year, April 15, June 14, September 1, and December 24, the equation of time is zero, that is, the apparent solar time is just the same as the mean solar time.

Cause of the Difference between Sidereal and Solar Day. Suppose, on a particular day, a star and the sun are on the meridian of a place at the same instant. The next day the star will come once more on the meridian at the same time, but the sun will not do so, as it will have in the mean-time moved about a degree *eastward*—a consequence of the earth's orbital revolution. It will, therefore, take the earth about 4 minutes more to turn through this degree and bring up the meridian to the sun. Thus the solar day is 4 minutes longer than the sidereal day.

226. Sidereal Year and Tropical Year. When a star and the centre of the sun cross the meridian of a place at the same time, the star and the sun are said to be in *conjunction*. After this, the sun will not come on the meridian at the same instant as the star, but later and later, until, after 365 days 6 hours 9 minutes 9 seconds, they are once more in conjunction. This interval is called the *Sidereal Year*." It is evidently the time taken by the sun to make a complete circuit of the sky in the ecliptic, or what comes to the same thing, the

time of revolution of the earth round the sun with reference to a star.

The "*Tropical* or *Equinoctial Year*" is the interval of time between two successive vernal or autumnal equinoxes. It consists of 365 days 5 hrs. 48 mins. 46 secs., so it is shorter than the sidereal year by about 20 minutes, on account of the precession of the equinoxes. (Art. 222.) Suppose that, in Fig. 95, V is the position of the vernal equinox, when the sun is seen in it on 21st March 1906. When the earth moves from E′ to E″, E‴, etc., the sun appears to move along the ecliptic from V to B, C, D, and so on. But, owing to the precession, the vernal equinox in the meantime will have shifted a little westward, so the sun will again meet it at V′ on 21st March 1907, *i.e.*, in less than a sidereal year.

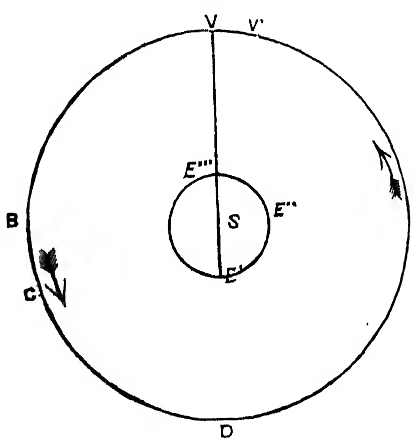


Fig. 95.—Sidereal and Tropical Years.

When the sun will again come to V, a sidereal year will be completed. This is why the tropical year is shorter than the sidereal year.

For ordinary purposes we use the tropical year, but, to be able to calculate easily, we take roughly 365 days in the year. This we call the "*Civil Year.*" However, to make it correspond with the tropical year, which consists very nearly

of 365¼ days, we add, every fourth year, one day, and count 366 days, in that year, calling it a *leap year*; so the average civil year is 365¼ days long. If the number of a year is divisible by 4, it is a leap-year. But four such years (3 common and 1 leap) contain 44 mins. 56 secs. more than four tropical years. Hence it is enacted that there should be only 97 leap-years in 400 years, the year rounding out a century (1500, 1600, 1800, 1900, etc.), if not divisible by 400, being not considered a leap-year.

LIST OF DEFINITIONS.

Aberration of Light is the minute apparent periodic displacement of the stars, due to the orbital motion of the earth combined with the motion of light.

Albedo. The light-reflecting power of a planet's surface is called its Albedo.

Altitude. The angular height of a celestial object above the horizon, measured by the arc of its vertical circle intercepted between it and the horizon, is called the Altitude of the object.

Annular Eclipse. That kind of solar eclipse in which the outer rim of the sun's disc continues to be visible, and only the central portion is eclipsed, is called an Annular Eclipse of the sun.

Antarctic Circle. The small circle parallel to the equator and $23\frac{1}{2}°$ from the south pole of the earth is called the Antarctic Circle.

Apex of the Sun's Way. The point in the sky towards which the sun moves with the Solar System, at the rate of about 11 miles a second, is called the Apex of the Sun's Way. This point is located near the star Vega in the constellation of Lyra.

Aphelion. The point in the orbit of a planet or a comet which is farthest from the sun is called its Aphelion.

Apogee is the point in the moon's orbit farthest from the earth.

The **Apparent or True Solar Day** is the interval between two successive transits of the sun over the meridian of a place. It varies throughout the year.

Arctic Circle. The small circle parallel to the equator $23\frac{1}{2}°$ from the north pole of the earth is called the Arctic Circle.

Asteroids or Minor Planets are a group of about 600 small planets, whose orbits lie between those of Mars and Jupiter.

The **Astronomical Day** is reckoned round through the whole 24 hours, *from noon to noon*, instead of being counted in two intervals of 12 hours each.

the zenith from the northern horizon.

Axis. The Axis of a heavenly body is the imaginary line about which it rotates.

Azimuth. The arc of the horizon between the south point and the foot of the vertical circle of a heavenly body, or the angle at the zenith between its vertical circle and the meridian, is called its Azimuth.

Binary Stars or Physical Couples. Those double stars which have a common centre of motion and move in elliptical orbits, in periods ranging from 5 to 1,500 years, are called Binary Stars or Physical Couples.

Calendar Month. The civil year of 365 days is, for ordinary purposes, divided into 12 months containing 28, 30 or 31 days. Such months are called Calendar Months.

The **Celestial Bodies** include the sun, the moon, stars, planets and their satellites, meteors, comets, the Milky Way, the nebulæ, and the Zodiacal Light.

Celestial Equator. (See **Equinoctial.**)

Celestial Meridian. The circle passing through the north and south points of the horizon of a place and through the zenith is called the Celestial Meridian.

Celestial Poles. If the axis of the earth be produced indefinitely both ways, it will cut the celestial sphere in two points called the north and south Celestial Poles. These two points do not participate in the daily motion of the heavens.

Celestial Sphere. The imaginary hollow sphere, on the inside surface of which the heavenly bodies seem to be situated, is called the Celestial Sphere.

The **Chromosphere** is the atmosphere of a brilliant scarlet colour, which immediately surrounds the sun, but which is visible only at a total solar eclipse.

Circles of Declination are small circles on the celestial sphere parallel to the equinoctial. They correspond to the circles of latitude on the earth.

The **Circles of Meridian** are great circles passing through the poles of the earth and cutting the equator at right angles.

Circumpolar Stars at a place are those which do not rise or set, but keep moving round and round the pole-star above the horizon.

The **Civil Day** consists of 24 hours, divided into two periods of 12 hours each, and is reckoned *from midnight to midnight.*

Civil Year. The year which is used for ordinary purposes and consists of 365 days is called the Civil Year.

Clefts. The narrow cracks, running hundreds of miles over the mountains and valleys of the moon, are called Clefts.

Clusters are collections of stars, containing hundreds and thousands of bright points.

Coma. The small, rounded, luminous cloud which forms the head of a comet is called the Coma.

Conjunction. The moon or a planet is said to be in Conjunction, when its elongation is 0°, *i. e.*, when the body is on the same side of the earth as the sun is.

Constellations are groups of stars named by the ancients after some familiar animal or object.

Corona. The beautiful halo of faint pearly light round the sun, consisting of streamers which extend to thousands of miles and seen during a total solar eclipse, is called the Corona.

Culmination. A heavenly body is said to Culminate, when in its apparent daily motion it comes to the meridian.

Day, (1) as opposed to night, is the interval of time between sunrise and sunset. (2) Day means the period of the earth's rotation on its axis, and consists of about 24 hours.

Declination. The angular distance of a heavenly body north or south of the equinoctial, measured along its hour-circle, is called its Declination.

Direct Motion is the motion of a heavenly body from west to east, *i. e.*, contra-clockwise, as seen from a point north of the ecliptic.

Double Stars are two stars which lie so close to each other that, to the naked eye, they appear as one star.

Earth-shine is the light reflected by the earth and illuminating the dark portion of the moon during the crescent phase.

Eclipse. When a luminous heavenly body (1) is obscured by a shadow falling upon it, or (2) when it is shut out from our view by the coming of an opaque body between us and it, it is said to be Eclipsed.

Ecliptic. The great circle of the celestial sphere which marks the apparent annual motion of the sun among the stars is called the Ecliptic.

Ellipse. The Ellipse is a figure bounded by a regular curve such that if two straight lines are drawn from any point in the curve to the two points within called its foci, the sum of the lengths of these lines is always constant.

Elongation. The angle formed at the earth by two lines drawn from it to the sun and a planet or the moon is called the Elongation of the planet or the moon.

Equation of Time. The amount which must be added to, or subtracted from, apparent solar time to obtain the mean solar time is called the Equation of Time.

Equator. The great circle on the surface of the earth at equal distance from the two poles and having its plane at right angles to the axis is called the Equator.

Equinoctial or Celestial Equator. The great circle of the celestial sphere 90° from either of the poles is called the Equinoctial or Celestial Equator. If the plane of the earth's equator be produced, the trace of its intersection on the celestial sphere will be the equinoctial.

Equinoxes. (1) The two points in the earth's orbit where the days and nights are equal all over the globe are called the Vernal and Autumnal Equinoxes. (2) The two points where the ecliptic and the equinoctial cut each other are also called Equinoxes, the one being known as the Vernal Equinox, or the Equinox of Aries, or the First Point of Aries, and the other the Autumnal Equinox or the Equinox of Libra. (3) The two dates in the year, 21st March and

22nd September, on which day and night are equal all over the globe, are likewise called the Equinoxes.

Evening Star. An interior planet is said to be an Evening Star, when it is visible after sunset in the west and sets before midnight.

Exterior or Superior Planets are those whose orbits lie without the orbit of the earth.

Faculæ are bright streaks on the sun's surface more brilliant than the photosphere, seen especially near the spots. They are supposed to be masses elevated above the general level, but of the same material as the photosphere.

First Point of Aries. One of the two points in which the equinoctial intersects the ecliptic, and where the sun crosses from the south to the north side of the equinotical on 21st March, is called the First Point of Aries.

First Quarter. When the moon appears half, about a week after it is new, it is said to be in the First Quarter, or at Quadrature.

Galaxy. (See **Milky Way.**)

Gibbous is the phase of the moon or a planet, when it appears more than half and less than whole.

Gravitation is the force by which all bodies or particles of matter in the Universe tend towards one another.

Gravity is the force which causes bodies on the surface of the earth as well as the moon to tend towards its centre. It is only a particular case of gravitation.

Great Circles are the circles of a sphere whose planes pass through its centre.

Horizon (Rational or Celestial). The great circle of the celestial sphere whose plane passes through the centre of the earth and is parallel to the sensible horizon is called the Rational Horizon.

Horizon (Sensible). The Sensible Horizon of a place is the circle in which a tangent plane drawn through the observer's eye intersects the celestial sphere.

Horizon (Visible). The line which bounds the part of the earth's surface visible to us from a given point, and where the earth and the sky appear to meet, is called the Visible Horizon.

Hour-angle. The Hour-angle of a celestial body is the angle at the pole between the celestial meridian and the hour-circle passing through the body.

Hour-Circles are great circles of the celestial sphere passing through the poles and, consequently, perpendicular to the equinoctial. They correspond to the meridians on the earth.

Inferior Conjunction. An interior planet is said to be in Inferior Conjunction when it is between the sun and the earth.

Interior or Inferior Planets are those whose orbits lie within the orbit of the earth.

Jets are spurts of luminous matter thrown out by the nucleus of a comet, as it approaches the sun.

Latitude. The angular distance of a place north or south of the equator, measured along its meridian, is called its Latitude.

Last Quarter. When the moon is half, about a week after the full-moon, it is said to be in the Last Quarter.

Librations are small, periodic changes in the position of the moon's surface with reference to the earth, in consequence of which small portions at opposite limbs become visible or invisible alternately.

Light-year. The distance travelled by light in one year ($186{,}000 \times 365 \times 24 \times 60 \times 60$ miles) is called a Light-year. It is the astronomical unit of stellar distance.

Limb is the border or edge of the disc of a heavenly body, particularly of the sun and the moon.

Local Time. The mean solar time of a place is called its Local Time.

Longitude. The distance of a place, measured in degrees or hours along the equator, east or west from a standard meridian is called its Longitude.

The **Lunar Day** is the interval between two successive transits of the moon across the meridian, and consists of 24 hours 51 minutes.

Lunar Month or Lunation (See **Synodic Month.**)

Magnitudes are the different classes into which stars are divided according to their degree of brilliancy. There are 18 such magnitudes.

Major Planets. The planets, Jupiter, Saturn, Uranus and Neptune, on account of their large size, are called Major Planets.

Mass is the quantity of matter that a body contains.

Mean Distance. The Mean Distance of a planet is half the sum of its greatest and least distances from the sun.

The **Mean Solar Day** is the average of the lengths of all the solar days in the year, and consists of 24 hours. It is reckoned from noon to noon without a break at midnight.

Meridian. The meridian of a place is the great circle which passes through the place and the poles of the earth.

Meteorites or Aerolites are masses of stone or iron, sometimes weighing several lbs, which occasionally fall on the earth from the sky.

Meteors or **Shooting Stars** are bright star-like points which shoot rapidly across the sky, leaving a luminous streak for a second or two behind.

Milky Way or Galaxy. The broad band or zone of faint light, stretching overhead in the sky like an arch and consisting of millions of stars, is called the Milky Way or Galaxy.

Minor Planets. (See **Asteroids.**)

Morning Star. An interior planet is said to be a Morning Star, when it rises between midnight and the following sunrise.

Nadir. The point where the direction of the plumb-line produced downwards strikes the celestial sphere under-foot is called the Nadir of a place.

Neap Tides. The unusually low tides which happen when the moon is in its Quarters are called the Neap Tides.

Nebulæ are dim cloud-like patches of light seen among the stars.

Nebulous Stars are those which are seen surrounded by a nebulous envelope.

Night is the interval of time between sunset and the next sunrise.

The **Nodes** are the two points where the orbit of the moon or a planet intersects the ecliptic.

Nucleus. The bright star-like point in the coma of a comet is called the Nucleus.

Nutation is the constant nodding or wavy motion of the earth's axis, or the approach and recession of the two poles towards and from the pole of the ecliptic, caused by the varying attraction of the moon on the protuberant mass of matter round the earth's equator.

Obliquity of the Ecliptic. The angle ($23\frac{1}{2}°$) between the plane of the equator and the plane of the ecliptic is called the Obliquity of the Ecliptic.

Occultation is the hiding of a heavenly body from our sight by the intervention of some other heavenly body. It is specially applied to the disappearance of stars and planets behind the moon, and of satellites of planets behind their primaries.

Opposition. When the earth is betweeen the sun and the moon or a planet, the moon or the planet is said to be in Opposition.

Orbit. The path in which a heavenly body revolves round another body is called its Orbit.

Parallax, in its broad sense, means the apparent displacement of a heavenly body caused by a change in the situation of an observer. However, it generally means the angle subtended at the object by the radius of the earth's orbit. When the object is on the horizon, the parallax is the greatest, and is called the *Horizontal Parallax.*

Parallelism of the Earth's Axis. The property of the earth's axis remaining parallel to itself in al parts of its orbit is called the Parallelism of the axis.

Parallels or Circles of Latitude are small circles on the earth parallel to the equator.

Partial Eclipse. That kind of eclipse in which a portion of the sun or the moon continues to be seen throughout the eclipse is called a Partial Eclipse.

Penumbra. (1) The faintly dark part of a shadow which surrounds the central intensely dark one is called the Penumbra. (2) The lighter border surrounding the dark central portion of a sun-spot is also called the Penumbra.

Perigee is the point in the moon's orbit where it is nearest to the earth.

Perihelion is the point in the orbit of a planet or a comet which is nearest to the sun.

Periodic Comets are those that move round the sun in elliptical orbits.

Periodic Time. The period in which a heavenly body makes one revolution round another is called its Periodic Time.

Perturbations are disturbances or deviations from the regular elliptical orbit of planets, caused by their attraction on one another.

Phases are the successive changes in the appearance of the moon or a planet during the period of its revolution.

Photosphere. The general bright surface of the sun, which we ordinarily see, is called the Photosphere.

Physical Couples. (See **Binary Stars.**)

Planets are the eight large spherical heavenly bodies which revolve round the sun.

Planetary Comets are the periodic comets which are found connected with any of the major planets.

Polar Compression. The difference between the lengths of the polar and equatorial diameters of a planet is called its Polar Compression.

Polar Distance. The angular distance of a heavenly body from either of the celestial poles, measured along its hour-circle, is called its Polar Distance.

Poles. The two points on a planet in which its axis cuts the surface, and which do not take part in the daily rotation, are called its Poles.

The **Pole-star** or **Polaris** is the star which is situated quite close to the north celestial pole, and about which the sky seems to rotate daily.

Precession of the Equinoxes. The slow westward shifting of the equinoxes on the ecliptic, caused by the conical revolution of the earth's axis round the pole of the ecliptic in 25,800 years, is called the Precession of the Equinoxes.

Primary Planets are those planets which revolve round the sun as their centre.

Prime Vertical The vertical circle passing through the zenith and at right angles to the celestial meridian is called the Prime Vertical.

Prominences or **Protuberances**. or **Red Flames** are huge masses of vapours usually of a scarlet colour, which are seen shooting up from the chromosphere of the sun and taking fantastic shapes.

Proper Motions. The *real* slow motions of stars relatively to one another, detected by delicate measurements taken at long intervals, are called the Proper Motions of Stars.

Quadrature. The moon or a planet is said to be in Quadrature, when the angle between the two lines drawn from the earth to the moon or the planet and the sun is 90°.

Radiant. The points in the sky from which meteoric showers seem to come on certain nights are called the Radiants.

Radius Vector. The line joining the sun and a planet or a comet at any point of its orbit is called the *Radius Vector*.

Rays are streaks which radiate from some craters of the moon like the spokes of a wheel, and pass across mountain and valley.

Refraction is the bending of a ray of light out of its original direction, while passing from one medium to another of a different density. When this refraction occurs in our atmosphere, it is called Atmospheric Refraction.

Retrograde Motion is the motion of a heavenly body from east to west, *i. e.*, clock-wise, as seen from a point north of the ecliptic.

Revolution. A body is said to revolve round another when its centre progressively moves round the other body.

Right Ascension. The distance, in time or degrees, of a heavenly body from the hour-circle of the First Point of Aries, measured along the equinoctial, is called its Right Ascension.

Rills are narrow, deep and crooked valleys seen on the moon, and supposed to be beds of dried-up streams.

Rotation. A body is said to Rotate, when a line drawn from its centre of gravity outward, through any point in its mass, (except the two lines passing through its poles) describes a circle in the heavens.

Saros is the cycle or period of 18 years and 11 days, after which interval the same eclipses recur.

Satellite. A small body which revolves round a primary planet, and accompanies it in its journey round the sun, is called a Satellite.

The **Seasons** are the changes in climate on a planet, occurring during its periodic time.

Secondary Planets. (See **Satellite.**)

Shadow. "When light falls on an opaque body, it cannot penetrate into the space behind it; this space is called the Shadow."

Shooting Stars. (See **Meteors.**)

Sidereal Day. The interval between two successive transits of a star across the meridian of a place is called the Sidereal Day. It is invariable, and commences at *Sidereal Noon, i.e.*, when the First of Aries is on the meridian.

Sidereal Month. The time that elapses between the moon leaving a certain star and returning to the same star is called a Sidereal Month. It consists of 27 days 7 hrs. 43 mins. 4 secs.

Sidereal Period. The time of a planet's revolution round the sun *from a star to the same star again, as seen from the sun*, is called its Sidereal Period.

Sidereal Time is the time indicated by an astronomical clock, which is so set that it shows 0 hrs. 0 mins. 0 secs. when the First Point of Aries comes on the meridian.

Sidereal Year. The interval of time between two successive conjunctions of the sun with a star, as seen from the earth, is called a Sidereal Year. It is, therefore, the time of revolution of the earth round the sun with reference to a star.

The **Small Circles** of a sphere are those whose planes do not pass through its centre.

Solar System. The group of heavenly bodies, consisting of the sun and the bodies which revolve round it as their centre, is called the Solar System.

Solstices. (1) The two *points* in the earth's orbit where it comes on the 21st June and 22nd December are called the Solstices. (2) The two *points* in the ecliptic, farthest from the equinoctial, where the sun seems to stand still in its north and south motion, are also called Solstices, (3) The word is also used for the two *dates* in the year, 21st June and 22nd December, on which the sun is most distant from the equinoctial.

Sphere. The Sphere is a solid body such that all points on its surface are equi-distant from a certain point within called its centre.

Spheroid. The Spheroid is the solid body generated by the revolution of an ellipse round either of its axes. An *Oblate Spheroid* is one whose polar diamater is shorter than its equatorial diameter. A *Prolate Spheroid* is one whose equatorial diameter is shorter than its polar diameter.

Spring Tides. The unusually high tides which occur at about new or full moon are called the Spring Tides.

Superior Conjunction. An interior planet is said to be in Superior Conjunction when the sun is between the planet and the earth.

Superior Planets. (See **Exterior Planets.**)

Synodic Month. The interval of time between two phases of the moon of the same kind, *e.g.*, between new moon and new moon, is called a Synodic Month. It consists of 29 days 12 hrs. 44 mins. 2 secs.

Synodic Period. The interval between two successive conjunctions of a planet *with the sun, as seen from the earth,* is called its Synodic Period.

The **Syzygies** are the two points in the moon's orbit where conjunction and opposition take place.

Temporary Stars or **Novæ** are such stars as blaze up suddenly where none existed before, and gradually fade away, until they become invisible.

Terminator. The imaginary circle which forms the boundary between the lit-up and dark hemispheres of the moon or a planet is called the Terminator.

Terrestrial Planets. Mercury, Venus, Earth, and Mars are called Terrestrial Planets, being bodies of the same order of magnitude as the earth.

The **Tides** are the regular rising and falling of the waters of the ocean twice in about 25 hours.

Total Eclipse. When the *whole* disc of an eclipsed body is obscured for some time, the phenomenon is called a Total Eclipse.

Transit. The passage of an interior planet across the disc of the sun, or of a satellite across the disc of its primary, so as to appear like a circular dark spot on the surface of the sun or the planet, is called a Transit.

Tropical or Equinoctial Year. The interval of time between two successive vernal or autumnal equinoxes is called a Tropical or Equinoctial Year.

Tropics. The circles of latitude 23½° north and south of the equator are respectively called the Tropic of Cancer and the Tropic of Capricorn.

Twilight is the faint diffuse light perceived before sunrise and after sunset, and caused by the reflection of sun-light by the solid particles in the higher regions of our atmosphere.

Umbra. The inner *dark* part of a shadow or of a sun-spot is called the Umbra.

Variable Stars are those which undergo a periodic change in their brightness.

Vertical Circles are great circles passing through the zenith and the nadir, and, consequently, perpendicular to the horizon.

The **Zenith** of a place is the point overhead in which the direction of the plumb-line, produced indefinitely, strikes the celestial sphere.

Zenith-Distance is the angular distance of a celestial body from the zenith, measured by the arc of its vertical circle intercepted between it and the zenith.

Zodiac. A narrow belt encircling the sky and 16° wide, (8° on each side of the ecliptic), to which the sun, the moon and the planets confine their wanderings, is called the Zodiac. It is divided into 12 equal parts, called the *Signs of the Zodiac.*

The **Zodiacal Constellations** are those which lie along the zodiac, and which the sun passes over in its annual round of the heavens. They are visible both in the northern and southern hemispheres of the earth.

Zodiacal Light. The faint conical mass of light, seen tapering upwards after sunset in spring, or before sunrise in autumn, from the point in the horizon where the sun sets or rises, is called the Zodiacal Light.

The **Zones** are the five belts into which the surface of the earth is divided, with respect to climate, by the Arctic and Antarctic Circles and the Tropics.

TEST QUESTIONS.

CHAPTER I.

1. What does Astronomy treat of?

2. Enumerate what are called the *Celestial Bodies*.

3. What is the *Celestial Sphere*? Contrast the ancient and modern views about its structure.

4. Explain the various uses and meanings of the term "*Horizon*."

5. What are the *Cardinal Points*? How can they be determined?

6. Describe the method by which we can determine the true north-and-south line by the sun.

7. Describe the phenomena of diurnal motion.

8. If you are in Bombay, how would the stars appear to move daily?

9. How would you find the true north celestial pole by circumpolar stars?

10. Explain the following terms, drawing diagrams to illustrate them:—

    The *sphere*, *zenith*, *nadir*, *celestial meridian*, *vertical circle*, *constellations*, *altitude*, and *zenith-distance*.

11. How is the apparent distance between two bodies in the sky measured?

CHAPTER II.

12. What is the true shape of the earth?

13. Give an experimental proof of the globular shape of the earth.

14. Explain clearly why ships disappear gradually when leaving a harbour.

15. Why do high objects like mountains or towers apparently diminish in height as we recede from them ?

16. How do the shape and extension of the horizon afford an evidence of the rotundity of the earth ?

17. What is the *pole-star* ? How can its position be determined ? Account for the fact that its altitude is different at different places on the earth.

18. Show how circumnavigation proves that our earth is round ?

19. What is the shape of the earth's shadow always observed at a lunar eclipse ? Give the reason.

20. What is the mean diameter of the earth ?

21. How do we know that the earth is, comparatively, a large body ? Why do we say that it is much smoother than an orange, in spite of its surface being broken by mountains and valleys ?

CHAPTER III.

22. Describe the apparent daily motion of the heavenly dome, and discuss the ancient and the modern theory proposed to account for this motion.

23. Describe the Tower-and-Stone Experiment. What can we infer from it ?

24. How did Foucault prove experimentally the rotation of the earth ?

25. Show that the present shape of the earth gives a proof of its rotation.

26. Though our earth really rotates, how is it that we do not feel the motion? Give an illustration or two.

27. Explain the terms *axis* and *poles of the earth*, *equator*, *parallels of latitude*, and *circles of meridian*, drawing a figure.

28. State the velocity and exact period of the earth's rotation.

29. Explain the phenomenon of *day and night*, drawing a diagram.

30. Why does the sun rise and set at different times at different places?

31. Summarise the effects of the earth's rotation.

CHAPTER IV.

32. State what you observe about the rising and setting points of the sun at different seasons.

33. Describe the sun's apparent annual motion among the stars.

34. How did the ancients attempt to explain the annual motion of the sun? Why is this view now discarded in favour of the modern one?

35. Explain, by the help of a figure, what causes the apparent annual movement of the sun.

36. What considerations lead us to conclude that the earth *revolves* round the sun?

37. How can the true shape of the earth's orbit be determined? Define *perihelion* and *aphelion*.

38. What is an *ellipse*? Show how it can be drawn. What is its most important property?

CHAPTER V.

39. What facts do you know about the axis of the earth ?

40. Explain clearly why the lengths of days and nights are unequal at different places on the earth at the same time, and at different times in the same place, drawing neat diagrams.

41. Fully account for the seasons, drawing the necessary figures.

42. Draw four sketches representing the appearance of the earth as seen from the sun at the Solstices and the Equinoxes.

43. Sum up briefly the consequences of the earth's revolution round the sun.

44. How many motions has the earth ?

CHAPTER VI.

45. Describe the daily motion of the heavens as seen from the north pole. What is the *midnight sun?* How is it caused ?

46. How do the daily movements of the heavenly bodies appear to an observer in Bombay ?

47. Show how the celestial bodies would appear to move daily at a place on the equator.

48. Contrast the apparent daily motion of the heavenly bodies as seen in London ($51°$ N.) and in Melbourne.

CHAPTER VII.

49. How much smaller is the moon than the earth ? What is the diameter of the moon ?

50. What observations show that the moon revolves round the earth ?

51. What is the shape of the moon's orbit? How is it determined?

52. Define the terms *nodes*, *perigee* and *apogee*.

53. Give the mean distance of the moon from the earth.

54. Explain clearly why the moon rises later every day. What is the average amount of its retardation?

55. Explain, by the help of a diagram, the phases of the moon.

56. What is *earthshine*?

57. Distinguish between *sidereal month* and *synodic month*, and show, by the help of a figure, why the latter is longer than the former.

58. Explain clearly, by a diagram, why the moon shows the same face to the earth, giving illustrations.

59. What are the moon's *librations*?

60. Explain the terms *mass* and *density*.

61. Describe the physical features of the moon revealed by the telescope.

62. What evidence is there to show that there is no water on the moon?

63. Describe the observations which prove that the moon has no atmosphere.

64. Why is life impossible on the moon?

CHAPTER VIII.

65. Explain the terms *shadow*, *umbra*, *penumbra*, and *eclipse*.

66. Explain by a figure the phenomenon of a lunar eclipse. Distinguish between a *total* and a *partial* lunar eclipse, and state the conditions under which they occur.

67. The moon often shines with a copper-coloured light, though it is completely eclipsed. Why is this so ?

68. State the conditions under which a total solar eclipse occurs, and explain by a diagram why it is not total at all places.

69. Describe the phenomena of a total solar eclipse.

70. Why are total solar eclipses observed so carefully ?

71. When does an annular eclipse of the sun occur ? Why is it so called ?

72. Can there be a solar eclipse seen partial at all places ? If so, show by a diagram when it can occur.

73. What is the greatest and the least number of eclipses that can occur in a year ?

74. Why are solar eclipses more frequent at a place than lunar ones ?

75. Show clearly why eclipses do not occur every month.

76. Contrast the characteristics of lunar and solar eclipses.

77. What rule enabled the ancients to predict eclipses ?

78. State briefly the consequences of the moon's revolution round the earth.

CHAPTER IX.

79. What do you know of the sun's figure ?

80. What is the distance of the sun from us ? Why is the determination of this distance regarded so important a problem in astronomy ?

81. State the diameter of the sun, and show how it can be experimentally determined.

82. How can you prove that the sun is made up of lighter materials than the earth ?

83. Describe the telescopic appearance of the sun at ordinary times.

84. Say what you know of the sun-spots.

85. How did Galileo discover the rotation of the sun on its axis ?

86. What do you know of the heat and light of the sun ?

87. What chemical elements have been found in the sun ? How can we know of their existence on our luminary ?

88. Describe the surroundings of the sun. When can they be seen ?

89. Give a summary of the physical constitution of the sun.

90. State the various theories about the sources of the sun's heat and light.

91. Mention the different motions of the sun.

92. Why is the sun so very important to the Solar System ?

CHAPTER X.

93. Give a list of the bodies composing the *Solar*] *System.*

94. What are *Interior* and *Exterior Planets* ? How can they be distinguished ?

95. Distinguish between *Terrestrial* and *Major Planets.*

96. What do you know of the apparent and real motions and the orbits of planets ?

97. Define *Direct Motion* and *Retrograde Motion.*

98. State and explain Kepler's Laws.

99. Explain the terms *elongation, conjunction, opposition* and *quadrature,* by a diagram.

100. When is a planet said to be a *Morning Star* and when an *Evening Star* ?

101. How can planets be distinguished from stars ?

102. Show how we can determine the length of the day and the seasons on a planet.

103. How can we on the earth ascertain the distance and diameter of a planet ?

104. What do you mean by the *mass* of a planet? How can it be determined ?

105. Can we detect the presence of an atmosphere on a planet ? If so, how ?

CHAPTER XI.

MERCURY.

106. State the distance, diameter, and the periods of rotation and revolution of Mercury.

107. Show by a diagram how Mercury or Venus shows phases as seen from the earth.

108. Why is Mercury exceptional in the Solar System ?

VENUS.

109. What do you know of the periods of rotation and revolution of Venus ?

110. State what you know of the brilliancy of Venus.

111. When and where can Venus be generally seen ?

112. When is Venus the Evening Star, and when the Morning Star ?

113. At what phase is Venus brightest? Show that its crescent forms part of a circle about six times larger than when it is full.

114. What do you know of the *transits* of Venus? Why are they observed so carefully? Can an exterior planet be in transit? If not, why not?

115. State what you know of the physical condition of Venus. What is its brilliancy due to?

MARS.

116. What is peculiar about the orbit of Mars?

117. When is it the best time to observe Mars?

118. Give a full account of the physical features of Mars, when viewed through a telescope, and state the inferences that have been drawn from them as to its physical condition.

119. How can you show that Mars has an atmosphere?

120. What is remarkable about one of the satellites of Mars?

121. What is your view about the habitability of Mars?

THE ASTEROIDS.

122. How were the asteroids discovered?

123. State the two theories advanced as to the origin of the asteroids.

JUPITER.

124. How many times is Jupiter larger than the earth?

125. Jupiter is almost as bright as Venus. Then how can they be distinguished from each other in the sky?

126. Describe the telescopic appearance of Jupiter.

127. What is the great brilliancy of Jupiter due to ?

128. What evidence have we for saying that Jupiter is still mainly gaseous and very hot ?

129. How many satellites has Jupiter ? Explain the phenomena of their eclipses, transits and occultations by a diagram.

SATURN.

130. What is remarkable about Saturn ?

131. State what you know of the rings of Saturn.

URANUS.

132. How was Uranus discovered ?

133. What is remarkable about the satellites of Uranus ?

NEPTUNE.

134. Narrate the circumstances which led to the discovery of Neptune. Why is this discovery regarded as a triumph of mathematical astronomy ?

135. What is the *Zodiacal Light* ? State the two theories proposed as to its nature.

136. What do you know of the *Gegenschein ?*

CHAPTER XII.

137. Describe the appearance and the constituent parts of a comet.

138. What changes does a comet undergo while revolving round the sun ?

139. How is the tail of a comet produced ?

140. What do you know of the volumes and masses of comets ?

141. In what respects do the orbits of comets differ from those of the planets ?

142. What are *periodic comets* and *short-period comets ?* State the "*capture theory.*"

143. What is the most probable theory of the constitution of a comet ?

144. Name the chemical elements detected in comets.

CHAPTER XIII.

145. What are *shooting stars* and *meteorites ?*

146. What do you know of the nature and motions of meteors ? When and why do we see meteors ?

147. Why have we a "*meteoric shower*" on certain nights in the year ?

148. Account for the 33¼-years' shower.

149. What reasons have we for saying that a comet is but the thickest part of a swarm of meteors ?

CHAPTER XIV.

150. What is the number of stars visible to the naked eye, and through the telescope ?

151. What is meant by the "*Star-magnitudes*" ?

152. On what do the brightness and colours of stars depend ?

153. How are distances of stars estimated ?

154. How can the dimensions of planets be found out? Can the same method be applied to stars?

155. Name the chemical elements detected in the stars. How are they found?

156. State all the apparent motions of the stars, and explain what they are caused by.

157. What do you mean by the "*proper motions*" of stars?

158. Define *variable stars* and *temporary stars*.

159. What are *double stars*, *physical couples* and *multiple stars*?

160. Explain:—*constellations*, *zodiac* and *zodiacal constellations*.

161. What do you know of the *Milky Way*?

162. What are "*clusters*"?

CHAPTER XV.

163. What is meant by *nebulæ*? How can they be distinguished from clusters and comets?

164. What do you know of the classes, shapes, number, and constitution of nebulæ?

165. State the *Nebular Hypothesis* of La Place. Why is it accepted by astronomers? What modification does Lockyer suggest in it?

CHAPTER XVI.

166. Explain, by a diagram, the following terms:—*celestial sphere*, *celestial poles*, *equinoctial*, *ecliptic*, *equinoxes*, and *hour-circle*.

If we want to fix the position of a star in the sky, we know?

168. Why is the determination of the positions of heavenly bodies very important?

169. Show how the geographical position of a place can be determined.

170. Explain :—*declination, right ascension, polar distance,* and *Sidereal Time.*

171. What do we mean by the *latitude* and *longitude* of a place? How can we determine our own latitude and longitude on land and on sea?

172. Prove geometrically that the latitude of a place is equal to the altitude of the pole-star at that place.

173. What is *local time?* How can it be found out?

174. What do you understand by *standard time?*

175. Say what you know of Indian Standard Time.

CHAPTER XVII.

176. What are the three inferences Newton deduced from Kepler's Laws?

177. Define "*gravitation.*" Enunciate and explain Newton's Law of Gravitation.

178. Show wherein lies the importance of the Law of Gravitation.

179. Show why the moon revolves round the earth.

180. How did Newton verify the Law of Gravitation?

181. What are *perturbations?* Why are their determinations so important?

182. Explain, by the help of a diagram, the phenomenon of *tides*

183. What are *spring* and *neap tides?* Show, by diagrams, how they are caused.

184. Explain the terms *priming* and *lagging*.

185. What is meant by *tidal friction*? State some of its effects.

CHAPTER XVIII.

186. Explain, by the help of a diagram, how the diameter of the earth is determined.

187. What is the true shape of the earth? Show how it is found.

188. Explain the phenomenon of *twilight*. Draw a diagram showing how long it lasts.

189. What is "*atmospheric refraction*"? How is it caused? Mention some of its astronomical effects.

190. What is meant by the "*precession of the equinoxes*"? Show how it is caused, and what its effects are.

191. Explain the term *parallax*. When is it the greatest? How is the parallax of stars determined? Why is the determination of parallax so important a problem in astronomy?

192. What is the moon's parallax? Describe carefully the method by which its parallax and distance are determined.

193. Mention the different methods used to determine the distance of the sun from the earth. State the most recently ascertained distance of the sun.

194. Explain the terms:—*sidereal day*, *apparent solar day* and *mean solar day*. Show why the solar day is longer than the sidereal day. What is *equation of time?*

195. Distinguish between *Civil Day* and *Astronomical Day*.

196. Distinguish between *sidereal year* and *tropical year*. How does the difference arise?

APPENDIX A.

Questions Selected from the Science Papers of the High Schools in the Bombay Presidency.

CHAPTER II.

1. Describe the position of the pole-star in the heavens. Why, as we journey northward from the equator, do we find this star to rise higher above our northern horizon ?

2. Give at least four arguments for the modern theory which accounts for the daily rotation of the heavenly bodies.

3. How do we know that the earth is very large, and that it is round ?

CHAPTERS III & IV.

4. Would it be right to say that the earth is at rest because the houses and trees upon it do not move ?

5. In what respects does the modern conception of the structure and motion of the celestial sphere differ from the ancient view ? Which do you prefer, and for what reasons ?

6. Distinguish clearly between 'Rotation' and 'Revolution.' What phenomena would be seen (1) if the earth had only the motion of rotation, (2) if it had only the motion of revolution ?

7. Describe the changes in the relative positions of the stars and the sun, and show how they could be explained by assuming the earth to revolve round the sun.

8. Describe the observations that show that the rotation of the earth is not its only motion.

CHAPTER V.

9. In what part of the sky is the sun at midday in June and December? What causes bring about these changes, and how do they operate?

10. Trace the changes in the length of day and night during the different parts of the year, and state what causes combine to produce them.

11. If the sun is nearer to the earth in winter than in summer, how is the greater heat of the summer days to be accounted for?

12. Give a diagram showing the relative positions of the sun and the earth when there is winter in Australia.

13. Describe fully the effects produced by the two motions of the earth.

14. What changes would a man observe in the length of days and nights and the seasons as he travels from the north to the south pole?

15. How do you account for the fact that we have winter when we are nearest the sun, and summer when farthest from the sun?

16. Explain clearly why in the northern hemisphere the days in summer are longer than the nights, and why at the equator they are equal throughout the year.

17. In our summer we have longer days and the heat is greater. At the poles the day is of six months' duration, and yet the polar regions are covered with snow. Explain carefully, using diagram where necessary, how you account for the fact.

18. What changes would be produced on the earth if the plane of the ecliptic coincided with the plane of the equator?

19. Assign reasons for the following:—

(*a*) The day and night are equal on all parts of the earth on September 23rd.

(*b*) People living within the Arctic Circle can see the sun at midnight.

20. How do we know that during the earth's journey in its orbit the different positions of its axis are parallel? What would be the consequences if the earth turned round the sun with its north pole always inclined towards the sun?

21. What are the consequences of the rotation and revolution of the earth? (See also Chapter III.)

22. What is the latitude of a place where the sun appears at noon on the zenith about the 22nd of December? (*Ans.* $23\frac{1}{2}°$ S.)

23. Describe the experiences, as regards the variation in the length of days and nights and in seasons, of a mariner who starts on a voyage from the south pole in the beginning of the tropical year (March 22nd) and reaches the north pole after the lapse of one year, travelling at a uniform rate.

CHAPTER VI.

24. If you go to London, what changes in the daily movement and the appearance of the starry heavens would you mark? Illustrate your answer with diagrams.

25. State and explain the position that the sun will occupy, if it be seen by an observer situated at the north pole throughout the year.

26. At a certain placc an observer finds that the circles of the daily courses of stars cut the horizon at right angles. What is the latitude of the observer? (*Ans.*—At the equator.)

CHAPTER VII.

27. Describe the present physical condition of the moon.

28. What changes would be marked on the moon, if the time of her rotation were different from that of her revolution?

29. Mention the different movements of the moon, describing carefully the observations by which they are detected.

30. Assign a reason to the following :—The moon appears to us sometimes larger and sometimes smaller in diameter.

31. How many times does the moon turn on its axis in a year ? (*Ans.*—About 13 times.)

32. How do we know that the moon is not self-luminous ?

33. The moon is seen rising at 3 A.M. one night, what is its phase ? (Waning crescent.)

CHAPTER VIII.

34. "Eclipses of the sun are more frequent than those of the moon. Yet at any one place more eclipses of the moon are visible than those of the sun." Explain the apparent paradox contained in the statement.

35. Describe carefully, giving diagrams, the positions of the sun, earth, and moon, at the time of solar and lunar eclipses. State the conditions requisite for the occurrence of an annular solar eclipse.

36. If the moon were to move in a perfectly circular orbit round the earth, what change would be noticed in the solar and lunar eclipses, and why ?

37. Describe carefully a total solar eclipse, and the observations made at the time regarding the surroundings of the sun.

38. A lunar eclipse lasts for three hours ; find out the part of the earth that sees the eclipse from the beginning to the end.

39. Can an eclipse of the moon occur at day-time ? Give reasons for your answer.

40. Can an occultation of Venus by the moon occur, during a lunar eclipse ? Would an occultation of Jupiter be possible under the same circumstances ? Give reasons.

42. Compare lunar and solar eclipses as to (1) their shape, (2) causes and conditions, (3) frequency and time of occurrence, (4) the area from which to be observed.

CHAPTER IX.

43. Show what sway the sun holds over the other members of the Solar System.

44. Comment on "All the world's work, with one trifling exception, is done by the sun, and man himself, prince or peasant, is but a little engine, which directs merely the energy supplied by the sun."

45. Explain fully how we conclude that "the sun-spots are hollows, eaten into the photosphere."

46. Describe the nature of the following :—Sun-spots, Red Flames, Corona. How does the spectroscope assist us in determining the elements present on the sun? Give a list of such elements.

47. Describe fully the telescopic appearance of the sun at ordinary times, and at the time of a total solar eclipse.

48. What is the sun made of? How has the length of its diameter been calculated? What are the dark spots on the sun? What discovery did they lead to regarding the sun?

49. Which class of the heavenly bodies does the sun belong to? Give a brief description of the appearance, movements, magnitude and physical condition of the sun.

50. Mention how the rotation of the sun on its axis can be ascertained by dwellers on the earth.

51. How do we ascertain that the photosphere does not mark the boundary of the sun's atmosphere?

CHAPTER X.

52. How will you determine whether a celestial body is a star or a planet ?

53. How does the inclination of the axis influence the seasons on the earth ? Name the planets, if any, where the seasons are similar to those on the earth, and any, where the seasons are uniform. (Also see Chapter V.)

54. What is meant by *phases* and *transits* ? What satellites perform transits ?

55. Explain how we ascertain whether a planet is interior or exterior.

56. A planet is seen 120° from the sun ; is it an interior or exterior planet ? Give reasons for your answer.

57. Can there be a transit of Mars across the sun's disc ? Give reasons.

58. A planet is seen high up in the sky at midnight. What phases can it show in a telescope ?

CHAPTER XI.

59. Assign reasons to the following :—

(1) Venus, though not a large planet, is the most brilliant object in the heavens.

(2) Venus is never seen in the heavens at midnight.

60. What is your view regarding the physical constitution of Jupiter ? Contrast the seasons of this planet and Mars.

61. Discuss how the presence of atmosphere and water on the different planets can be determined by an observer on the earth. What is the result of such investigations with regard to Venus, Mars, Saturn and our moon ?

64. Describe the appearance of Mars and Jupiter as seen through a telescope.

65. Assign reasons to the following :—

(*a*) Venus is sometimes seen in the morning and sometimes in the evening but never seen at midnight.

(*b*) Mars is never seen in a crescent form.

66. Mention how the existence of snow on Mars can be ascertained by dwellers on the earth.

67. How have astronomers ascertained the diameter and weight of Jupiter ? Show how these measurements point to some fundamental contrast between the constitution of Jupiter and of the earth. What telescopic observations of its surface seem to justify the theory of the present condition of the planet ?

68. Sketch (*a*) Mercury in superior conjunction.

(*b*) Venus in inferior conjunction.

(*c*) Jupiter in opposition.

(*d*) One of Jupiter's satellites occulted and another eclipsed.

CHAPTER XII.

69. Notice the various points of resemblance and difference between comets and planets.

70. Mention how the extreme thickness of the tail of a comet can be ascertained by dwellers on the earth.

CHAPTER XIII.

71. What is the relation between comets and meteors ?

72. What do you know about the meteors, and the connection between them and the comets ?

73. What are Meteoric Showers? How are they caused? Give the names and dates of some of the more common ones.

CHAPTER XIV.

74. Discuss those apparent movements of the stars that cannot be explained by the rotation or revolution of our earth.

75. What are *Double* and *Multiple Stars*? What is a *star-cluster*? How does it differ from a *Nebula*?

CHAPTER XV.

76. What is the relation between planets and nebulæ?

77. "In the heavens we thus see the whole course of evolution run, from the primeval haze just condensing and getting hot, to the dark, silent star, that has run its course of life." Explain clearly the hypothesis to which the above remark alludes.

CHAPTER XVI.

78. What is right ascension, and how is it measured? What corresponds to right ascension on the earth's surface?

79. When it is 11-30 A.M. at Bombay, long. 72° $45'$ E., it is 2-23 P.M. at Hongkong; find the longitude of the latter place.

Solution:—Since it is 11-30 A.M. at Bombay when it is 2-23 P.M. at Hongkong, the difference between these times is 2 hrs. 53 min. Hence the difference between the longitudes of Bombay and Hongkong is $2\frac{53}{60}\times 15^\circ = 43^\circ$ $15'$. But the longitude of Bombay is 72° $45'$ E, therefore the longitude of Hongkong is $43^\circ\ 15' + 72^\circ\ 45' = 116^\circ$ E.

80. A star, whose north polar distance is 17°, passes the meridian at a certain place 3 hours after the First Point of Aries. Find out the declination and the right ascension of the star.

declination of the star is $90° - 17° = 73°$ N.

Again, since the star passes the meridian 3 hours after the First Point of Aries, the right ascension of the star is also 3 hours.

81. It is said that mariners, in the midst of a great ocean where nothing but sky and water is visible, can determine their own position by observations of stars; how can it be done?

82. How would you find the latitude of Bombay?

CHAPTER XVII.

83. Give Newton's Law of Universal Gravitation. If the force of gravity at the surface of the earth be represented by unity, by what should it be represented at the distance of the moon?

84. Neptune's place was determined before it had been ever seen. State the laws which led to the discovery.

CHAPTER XVIII.

85. Assign reasons to the following:—

(*a*) The solar days are not all of the same length.

(*b*) The constellation Aries is no longer in the Zodiacal Sign of Aries, as it was in the time of Hipparchus, some 2,000 years ago.

APPENDIX B.

Questions Set at the Matriculation Examination of the Bombay University.

[The numbers in bracket at the end of the questions refer to the Articles.]

1881.

1. Give all the proofs you know of the Rotundity of the Earth, and its Rotation on its axis. (11, 16.)

2. What changes would be produced on the Earth, if its axis were to place itself at right angles to the plane of the Ecliptic? (27, 28.)

3. Explain the causes of solar and lunar Eclipses. Why do they not occur every lunar month? Why is a total solar eclipse visible only on a small portion of the Earth's surface? (55, 56, 57.)

1882.

1. What is meant by longitude and latitude of a place? Why are degrees of longitude and latitude not equal in length? Why is noon at Madras half an hour earlier than in Bombay? (209, 210.)

Ans.—The degrees of latitude are not all of equal length, because the earth is not a perfect sphere, but an oblate spheroid. Again as the circles of meridian meet at the poles, a degree of longitude gradually decreases in size as we go from the equator to the poles.

2. How are Tides occasioned? Explain Spring and Neap Tides. (218.)

1. Distinguish between apparent and mean noon, and give approximately the greatest difference between them. (225.)

2. Explain the phenomena of the Seasons. (28.)

1884

1. What is the cause of an eclipse of the Moon? Why is it always Full Moon when an eclipse takes place? (56.)

2. Explain the cause of the Tides. Why does the Tide not always rise to the same height? (218.)

3. Show, by a diagram, how the geographical position of a place is determined when its latitude and longitude are known. (209, 210.)

1885.

1. Name the bodies comprised in the Solar System. Distinguish between Primary and Secondary Planets (85 and List of Definitions).

2. If a ship sailing due west at a uniform rate, circumnavigates the earth in 600 days, what will be the interval of time between any two successive noons on board the ship?

Solution.—In 600 days the ship traverses 360° due west,

therefore „ 1 day „ „ $\frac{3}{5}^{0}$ „ „

But the earth rotates, from west to east, 360° in 1 day, so the sun takes 24 hours to return to the same meridian, *i.e.*, the interval between any two successive noons would be 24 hours, if the ship did not sail, due west, $\frac{3}{5}^{0}$ in 24 hours. Therefore the sun has to travel each day $\frac{3}{5}^{0}$ more in order to be again on the meridian. Hence $360^{0} : \frac{3}{5}^{0} :: 24$ hrs: $\frac{1}{25}$ hr. = 2 min. 24 sec. Therefore the real interval between two succesive noons is 24 *hrs*. 2 *mins*. 24 *secs*. *Ans*.

3. When is an eclipse of the sun possible? Why is not a total eclipse observed at all places where the sun may be visible at the time? (57, 62.)

1886.

1. State the three Laws of Kepler, and mention what important conclusion Newton arrived at from the third law. (92, 213.)

2. Which of the planets are attended by satellites ? Name them and say how many has each. (85.)

3. Give the general conditions under which eclipses, lunar and solar, occur ; and explain clearly why we have sometimes partial and at other times total eclipses. (55, 56, 57, 61.)

1887.

1. When is Venus the morning and when the evening star ? Why have the transits of this planet been observed with so much care ? (112,114.)

2. How many times is Mars smaller than the earth ? Describe its general appearance as seen through a telescope. (116, 119.)

3. Give two of the most obvious and convincing proofs of the rotundity of the Earth, and state clearly why the days and nights are unequal in length in different parts of the world. (11, 27.)

1888.

1. Enumerate all the different bodies that constitute the Solar System. Mention at least two particulars in which stars differ from planets. How do you distinguish between stars and planets at night ? (85, 95.)

2. Explain fully, using a diagram, the phases of the moon. (41.)

3. How do you account for the fact that the tide rises and falls twice daily ? (218.)

1. Explain how the experiment of letting fall a stone or other heavy object, from the top of a high tower, may be employed to prove that our Earth revolves on its axis. Mention briefly two other considerations that point to the same conclusion. (16.)

2. Mention, without explaining, two methods that have been used to ascertain the distance of the Sun. What are the dark spots of the Sun? What discovery did they lead to regarding the Sun? (224, 75, 76.)

3. What is meant by an eclipse of the Moon? Explain the occurrence of the Phenomena by a diagram. Why does the Moon always present the same half of her surface to the Earth? (56, 45.)

1890.

1. Mention the various bodies that constitute the Solar System, dividing the planets under their proper head, Exterior or Interior, and state opposite each the number of its moons. (85, 86.)

2. What is meant by a Transit of Venus? (114.)

3. An Eclipse of one of Jupiter's moons took place at 11 A.M. at Greenwich, the phenomenon being observed at another town at 2 P. M. of its local time; find the longitude of the latter place.

Solution :—The difference in times being 3 hours, the difference in longitude is $3 \times 15^\circ = 45^\circ$. As the time at the latter place is in advance of Greenwich time, the longitude of the place is East. *Ans.* 45° E.

4. Explain the following :—Ecliptic, First Point of Aries, Retrograde Motion, Occultation, Right Ascension, and Satellite. (*Cf.* List of Definitions.)

1891.

1. Give a general outline of the Solar System, mentioning all the planets, with their satellites, in order of their distance from the sun. (85.)

2. Explain with a diagram the change of seasons. (28.)

3. Explain the phases of the Moon. (41.)

1892.

1. What is the reason that an Eclipse of the Sun can only take place at New Moon, and an Eclipse of the Moon only at Full Moon? (57, 56.)

2. What is the sun made of? How has the length of his diameter been calculated? (78, 80, 72.)

3. Define in separate paragraph the following terms :—Polar Distance, Declination, Latitude and Longitude. (*Cf.* List of Definitions.)

1893.

1. Explain clearly why, as a rule, the days and nights are unequal, and show that in two positions of the Earth's orbit the days and nights are equal all over the globe, and that at the equator they are equal throughout the year. (27, 28.)

2. Describe the appearance of Jupiter as observed with a telescope, and explain by means of a diagram the phenomena of occultations and eclipses of its satellites. What is the number of Jupiter's satellites? (132, 135.)

3. Define (1) the First Point of Aries, (2) inferior and superior conjunctions of a planet, and (3) conjunction and opposition of a planet. (*Cf.* List of Definitions and 93.)

4. Explain how to find out by observation whether a planet has its orbit within or without that of the Earth. (87.)

1894.

1. What facts go to prove that the earth travels round the sun once in a year? Describe an experiment illustrating this. (22, 23.)

2. Explain how the seasons depend upon the difference in the length of the day and night. (28.)

3. Explain clearly why the moon changes her form from a crescent to a circle. (41.)

4. What fact prevents the monthly eclipses of the sun and of the moon? (63.)

1895.

1. Mention all the motions of the Earth, explaining the various astronomical phenomena produced by them. (14, 19, 22, 28, 31, 188, 222.)

2. (*a*) What are meteorites and meteors? What are the grounds for saying that comets are but swarms of meteorites? (173, 174, 175, 178.)

(*b*) How are astronomers able to determine the length of a planet's day? (96.)

3. While observing Jupiter at different times, you see one of the satellites (1) apparently touching the disc of the planet and gradually disappearing, (2) disappearing while it is yet at some distance from the disc and (3) suddenly making its appearance some way off from the disc. Explain these phenomena with the help of a diagram. (135.)

1896.

1. Give a brief and general description of the Solar System. (85.)

2. How are solar eclipses caused? When should we have a partial solar eclipse, a total solar eclipse, and an annular eclipse? Why are lunar eclipses seen from a greater portion of the earth's surface than solar eclipses? (57, 60, 61, 62.)

3. Explain how an interior planet in its path round the sun should vary in size and shape as seen from the earth. By what simple experiment would you illustrate your explanation? (106, 113.)

1897.

1. (*a*) Describe the appearance of the moon as seen through a telescope. (49.)

(*b*) Fully account for the phases of the moon, drawing neat diagrams in illustration of your explanation. (41.)

(*c*) Mention, but do not describe or explain, any other phenomena caused by the revolution of the moon round the earth. (67.)

2. How are the positions of the heavenly bodies determined? Why are these determinations of great practical importance? (206, 207.)

1898.

1. What would happen if the Earth's axis were perpendicular to the plane of the ecliptic? Give reasons for your answer. (27.)

2. What are sun-spots supposed to be? What kind motion do they appear to have? What does that motion indicate? What changes in their appearance do they present as they move along, and how would you represent these changes by a simple experiment? (75.)

3. Explain how the eclipses, occultations, and transits of Jupiter's satellites take place. Draw a neat figure to illustrate your answer. (135.)

1899.

1. (*a*) Draw a diagram to illustrate approximately the distances, dimensions, and orbits of the planets and other bodies constituting the Solar System. (*Cf.* Frontispiece.)

(*b*) State fully what you know about Lunar Eclipses. (56.)

2. Define *gravitation*. Enunciate the laws of gravitation. (213.)

Explain the principle of the calculation by which Newton proved the law of gravitation with reference to the motion of the moon round the Earth. (216.)

1900.

1. (*a*) Fully describe and account for the apparent motions of the moon. Describe a simple experiment and draw a neat diagram in illustration of your answer. (38, 46.)

(*b*) Clearly explain why the moon changes her form from day to day. (41.)

2. State fully what you know about comets and meteorites. (161 to 178.)

1901.

1. State fully what you know about Solar Eclipses, drawing, as far as possible, neat figures in illustration of your statements. (57, 59, 60.)

2. Explain precisely how astronomical observations help us to determine the longitude of places on the earth's surface. (210.)

1902.

1. (*a*) Define Conjunction; Phase; Transit. (*Cf.* List of Definitions.)

(*b*) Why are the Interior Planets so called? (86.)

State fully what you know about the rotation, revolution, phases, seasons, and the apparent size of each of the Interior Planets. (104, 106, 108, 109, 113, 115.)

2. Account for the variations in the length of days and nights, and fully explain how the seasons are caused. (27, 28.)

1903.

1. Why do eclipses not take place every month? Explain the occurrence of lunar eclipses with the help of a diagram. Describe the different kinds of solar eclipses. Make a sketch in black and white of the appearances of the sun's disc during the progress of (1) total, (2) partial, (3) annular eclipses of the sun. (63, 56, 57, 60, 61.)

2. Write all you know about—(1) sun-spots, (2) comets, (3) the Milky Way, (4) nebulæ. What reasons have you for saying that comets are swarms of meteorites. (75, 161 to 172, 196, 198 to 201, 178.)

1904.

1. Explain the following terms:—Transit, occultation, Gibbous, First Point of Aries. (*Cf.* List of Definitions.)

2. Suppose an eclipse of one of Jupiter's moons was observed to take place at Greenwich at 2 P.M.; while it was seen at two places A and B at 1 P.M. and 3 P.M. respectively. Find the longitudes of A and B.

Solution:—The difference between the local time of A and that of Greenwich is 1 hour; therefore the longitude of A is 15°. Since the time of A is behind G. time, its longitude is 15° W.

Similarly, the longitude of B is 15° E, because its local time is 1 hr. in advance of G. time.

3. Give the names of every body that is included in what is known as the Solar System. What is meant by "interior" and "exterior" planets? Name the former. (85, 86.)

4. Draw two sketches to illustrate what is meant by "inferior" and "superior" conjunction. (93.)

1905.

1. What is the size of our earth? What is its distance from the sun? (13, 70.)

Describe any experiment to prove that our earth is rotating on its axis. What is the velocity of the earth's rotation? (16, 18.)

2. To what are the heat and light of the sun due? How has the size of the sun been determined? What are sun-spots? (81, 72, 75.)

3. How far is the moon from us? (39.)

To what is its light due? Why is it that the same half of the moon is always turned towards the earth while the other half is never seen by us? (44, 45.)

1906.

1. State what you know about the sun's appearance, distance from the earth, and magnitude. (74, 75, 70, 71.)

Show by a diagram how to account for the phases of the moon. (41.)

2. Explain the following terms :—

Ecliptic, right ascension, universal gravitation, aphelion, perigee, equation of time. (*Cf.* List of Definitions.)

Draw neat sketches to illustrate clearly the following three phenomena, taking care to name all the essential parts of your drawings :—

(*a*) Total eclipse of the sun. (57.)

(*b*) Annular eclipse of the sun. (60)

(*c*) Eclipse of the moon. (56)

3. Why does noon at Bombay occur about an hour later than at Calcutta? What relation roughly does the Indian Standard Time bear to Bombay and Calcutta times? (210, 211.)

How would you determine the latitude of Bombay? (209.)

4. Mention some reasons why we believe that our earth is rotating on its axis. (15, 16.)

Draw the figure given in your text-book to illustrate the fact that the two motions of the earth are not in the same plane. What fact in nature results from this non-coincidence? (27, 28.)

1907.

1. What is the mean diameter of the earth and what is its distance from the sun? (13, 70.)

Define terrestrial pole, equator, and parallels of latitude. (17.)

2. When it is 12 noon at Bombay it is 1h. 34m. P. M. at Rangoon. The longitude of Bombay being 72° 49′ east of Greenwich, find the corresponding time at Greenwich and the longitude of Rangoon.

3. There is a daily retardation in the time of the rising of the moon. What is the amount in time roughly of this retardation? Explain the phenomenon. (40.)

4. What are sun-spots, chromosphere, corona, and red flames? Name some of the principal elements observed in the sun. How has the existence of these elements in the sun been proved? (75, 79, 78.)

5. State fully what you know about Comets and Meteors. (161 to 171, 173 to 178.)

REVIEWS AND OPINIONS.

This is an exceedingly clear and useful manual, compiled evidently by an enthusiast. There is, of course, nothing new in the text, but the explanations are clear, and the book is well printed throughout. Its most notable feature, however, is the illustrations, which number nearly 100, and include everything, even celebrated telescopes and great astronomers. They are admirably printed............. and make the path as clear, both for the teacher and learner, as it is possible for a path to be. We wish the book every success.—*Indian Education.*

The book is well written and the diagrams are numerous. There are portraits of great astronomers. The moon and its surface, the sun and his spots, photosphere, corona, and prominences are illustrated by beautiful pictures, as are also the Great Nebula in Orion and the Zodiacal Light.—*The Educational Review (Madras).*

I have great pleasure in saying that the Manual of Matriculation Astronomy seems to be a very useful compilation and is sure to prove useful to the students for whom it is intended. It contains numerous diagrams and plates which are very well conceived and executed. In short, I can heartily congratulate its author, Mr. Kharas, on the conception, preparation, and get-up of his little book.

R. P. PARANJPYE, B. Sc., M. A.,
Principal, Fergusson College.

I have seen Mr. Kharas' book on Astronomy for the use of Matriculation students. It is correctly and intelligently written; and a creditable effort has been made to bring the astronomical problems, so far as they could be brought, within

the comprehension of school-boys. I find that many school-masters have found it helpful to them in teaching. The diagrams are numerous and interesting.

JAMSHEDJI A. DALAL, M.A., LL.B.,

Late Principal, Gujarat College, and University Examiner.

MR. KHARAS' Manual of Astronomy is well adapted to the requirements of candidates preparing for the Matriculation Examination of the Bombay University. The illustrations are numerous and excellent, and the author has utilized his experience as a teacher in rendering the subject easily intelligible to beginners.

JAMSHEDJI E. DARUWALLA, B.A., B.SC.,

Acting Principal and Professor of Mathematics,

Gujarat College.

At a cursory glance it seemed to me a very useful book, the explanations clear and the illustrations very well chosen. I shall not fail to recommend the book to my Matriculation students.

A. MARTIN, S. J.,

Principal, St. Xavier's High School.

I have to thank you sincerely for the present of a copy of your precious Manual of Matriculation Astronomy. My pupils have been allowed preparation-time, but I shall be happy to draw their attention to your useful book when they come back.

KER. NANJIANI, B. A.,

Headmaster, Broach High School.

.... The get-up of the work is excellent, the diagrams are very neat and clearly illustrate the several facts and phenomena of Astronomy. They will be a great help to

students in arriving at some of the obscure conceptions of Astronomy. I wish you every success in your attempt to give the subject of Astronomy a clear and intelligible form.

GIRDHARLAL B. MODI,

Headmaster, Pattan High School.

I am happy to inform you that I am introducing it as the Text-book from January 1907....... Your book will do away with the necessity of giving notes and the reading of two books, a thing undesirable for students. Your book is also full of illustrations and the reading is easy, and I have no doubt it will amply meet the requirements of the Matriculation curriculum of the Bombay University.

A. A. FERREIRA, B.A., LL.B.,

Principal, A. Da Silva High School, Dadar.

Students in the present day have much to be thankful for. Instead of the heavy uninteresting times that had to be waded through to gain information in olden days, neat little hand books, beautifully illustrated, and so clearly and lucidly written that the densest could not fail to acquire knowledge from them, are supplied. Such a book is the one Mr. Kharas has at infinite trouble prepared not for students only but any one interested in Astronomy. Each subject is taken separately. The Planets, for instance, have a chapter devoted to them with full-page illustrations, with, of course, a portrait of Sir William Herschel. With the chapter on gravitation is a portrait of Sir Isaac Newton, and a most apt quotation :—

Nature and Nature's laws lay hid in night,
God said 'Let Newton be,' and all was light.

A chapter of Definitions of the Astronomical words completes a most interesting and instructive book.—*The Bombay Gazette.*

We have received an excellent little Manual of Astronomy, prepared for the Matriculation curriculum of the Bombay

University by Mr. D. B. Kharas, Joint Principal of the Fort and Proprietary High Schools. A better book for students we have not seen. Not only does it compress its instruction within reasonable limits (there are only 150 pages, all clearly printed), but the book is made thoroughly attractive by diagrams and other illustrations, a very pleasing feature being the portraits of the great astronomers of all the ages. There are also a valuable appendix containing several pages of definitions, which should make the mastery of the book a matter of comparative ease, sets of questions on the various chapters and topics, and the examination papers for Matriculation students in past years. Mr. Kharas has been very conscientious in the preparation of his little book, and has consulted the most recent works of eminent authorities on the science of the stars. While it is specially designed for elementary students, his book may be profitably read by those who have already a friendly acquaintance with the investigations of astronomers. For the modest sum of Re. 1-4 it is certainly a very safe scholastic investment.—*The Advocate of India.*

A *Manual of Matriculation Astronomy* by D. B. Kharas is an up-to-date and useful compilation, and is crowded with illustrations. The treatment is able and lucid......

The Indian Spectator.

..... The work abounds in many important features, foreign to the majority of the compilations which cram the shelf of the book-seller, and would be welcome alike to the teacher and his pupils. To the former it will prove a useful acquisition, for it will spare him much of the bother and worry of compiling notes and supplying the deficiencies of the prescribed text-book of the school; to the latter it would serve as a *vade-mecum* which must accompany him as a faithful guide to the end of his matriculation career......Happy enough, the book errs neither on the side of profusion nor of deficiency......There is, moreover, another difficulty which confronts the Indian students, particularly in the study of scientific subjects, and which has been very successfully overcome by the work under review. The majority of the High Schools of the Presidency have no laborataries to speak of, and are otherwise inadequately equipped.

Mr. Kharas has attempted to meet this deficiency by a profusion of illustrations. Almost every page is illustrated with appropriate diagrams and plates,..neatly executed......The author has spared no pains and expenses to make the work a popular text-book......We warmly recommend it as a text-book in private and Government High Schools......We do not think Mr. Kharas's work needs any puff from the press to push up its sale. The work has a value of its own which will appeal readily to the average student who is, more frequently than not, gifted with a keen and appreciative eye in the discrimination of his text-books.—*The Rast Goftar.*

MR. DOSABHAI B. KHARAS, B.A.,......has done a service to the student world by publishing a serviceable "Manual of Matriculation Astronomy." It is written in clear, simple style and contains up-to-date information on the subjects it treats of. The diagrams are all well executed, and the printing and get-up of the book all that can be desired. We have no hesitation in recommending the book not only to the student world but also to all those who wish to equip themselves with a tolerable knowledge of Astronomy in a small compass.—*The Parsi.*